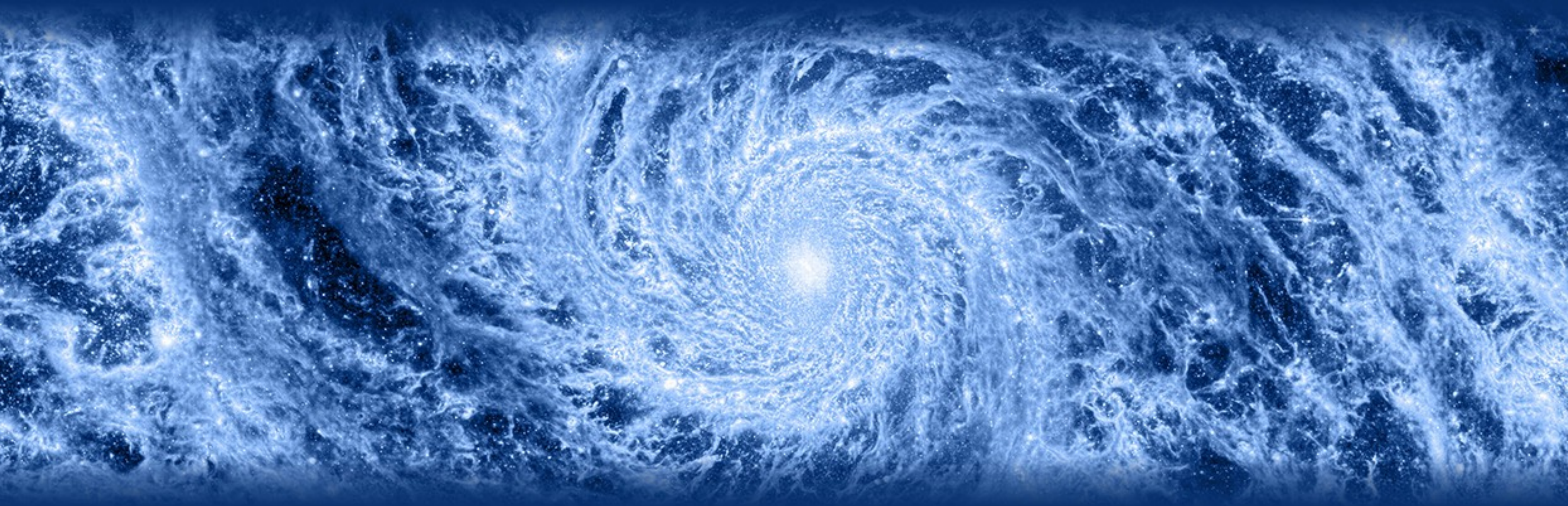
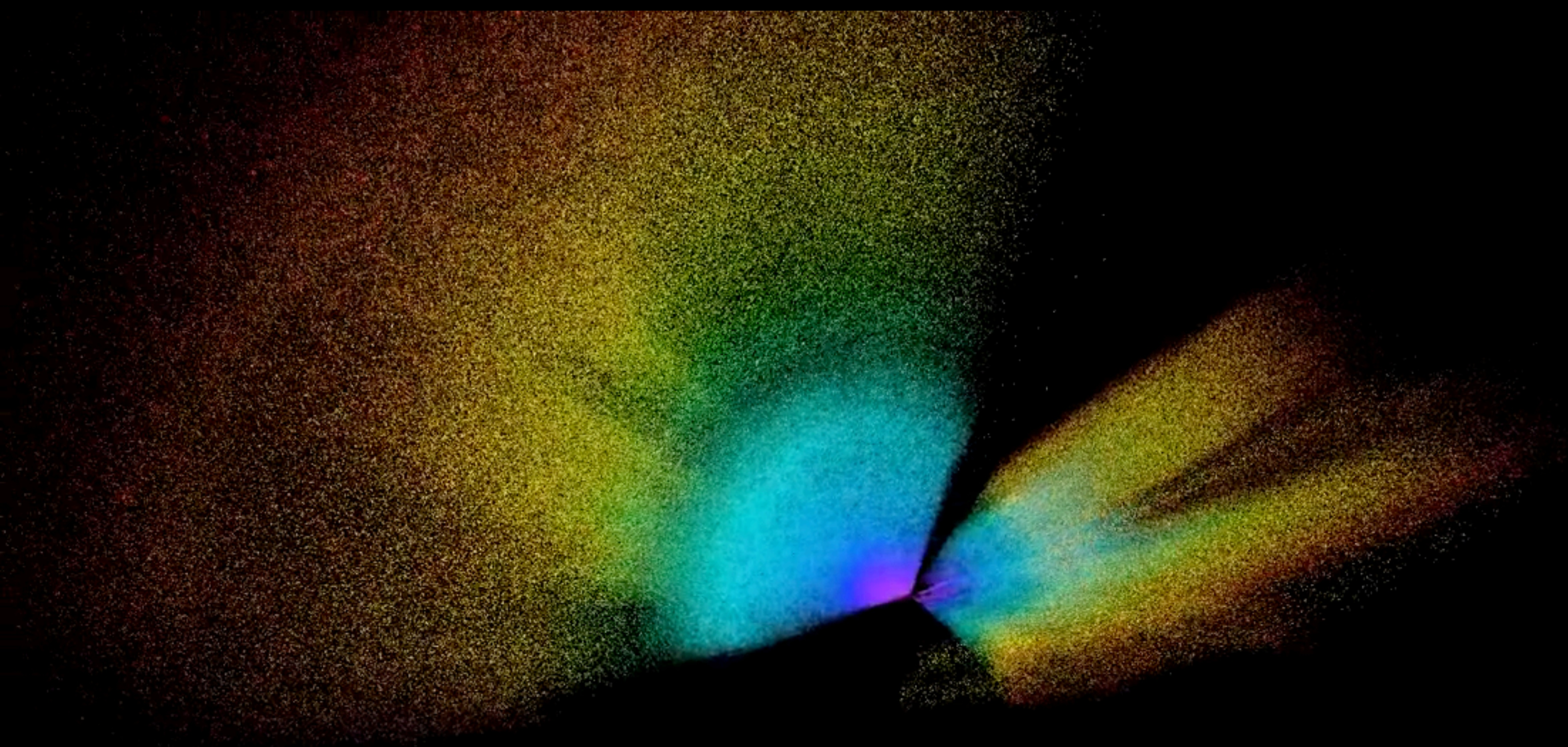
Galaxies

Prof. Benedikt Diemer



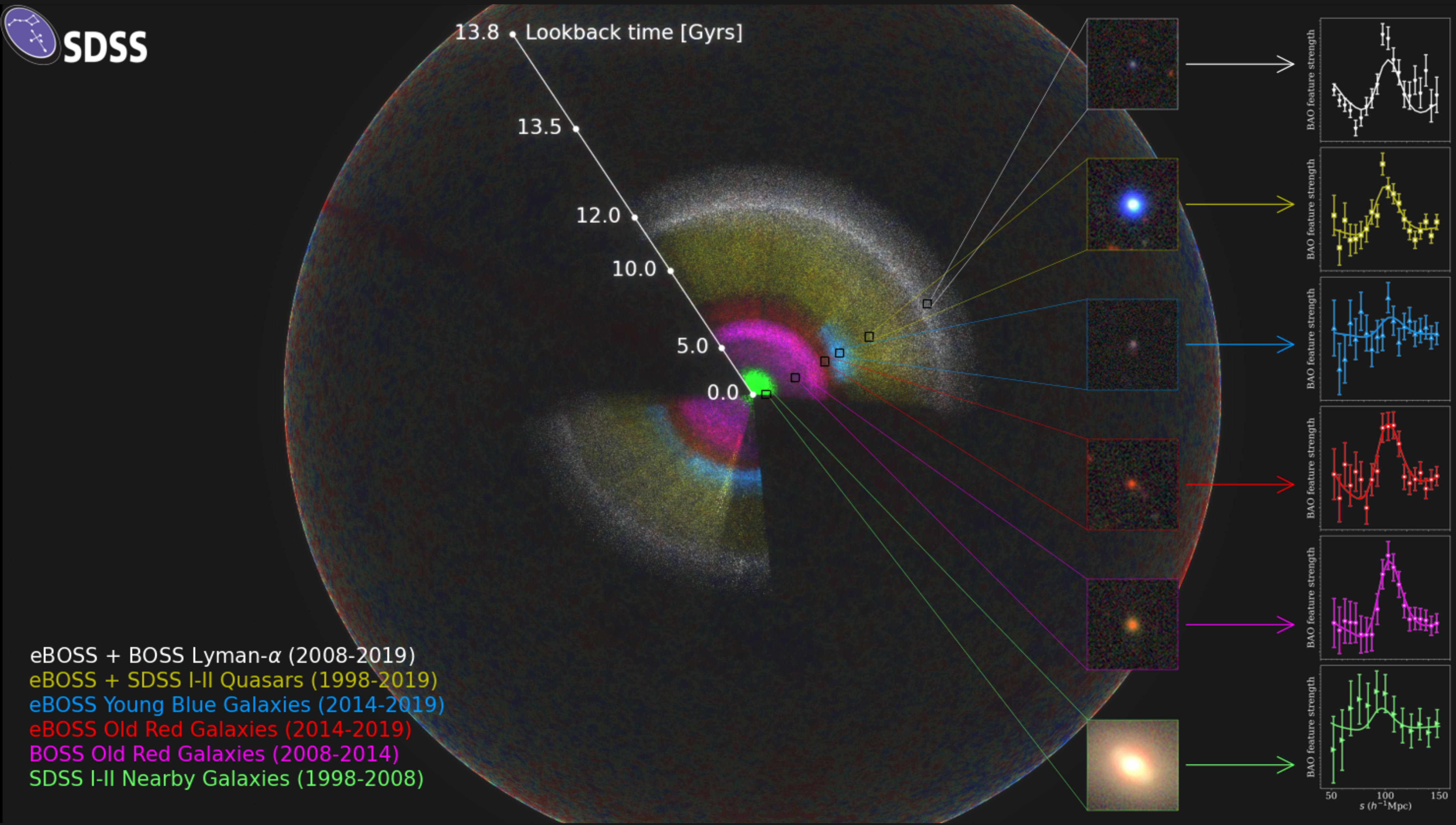
Chapter 2 • Galaxies in the SDSS survey

§2.1 • Distribution in real and redshift space



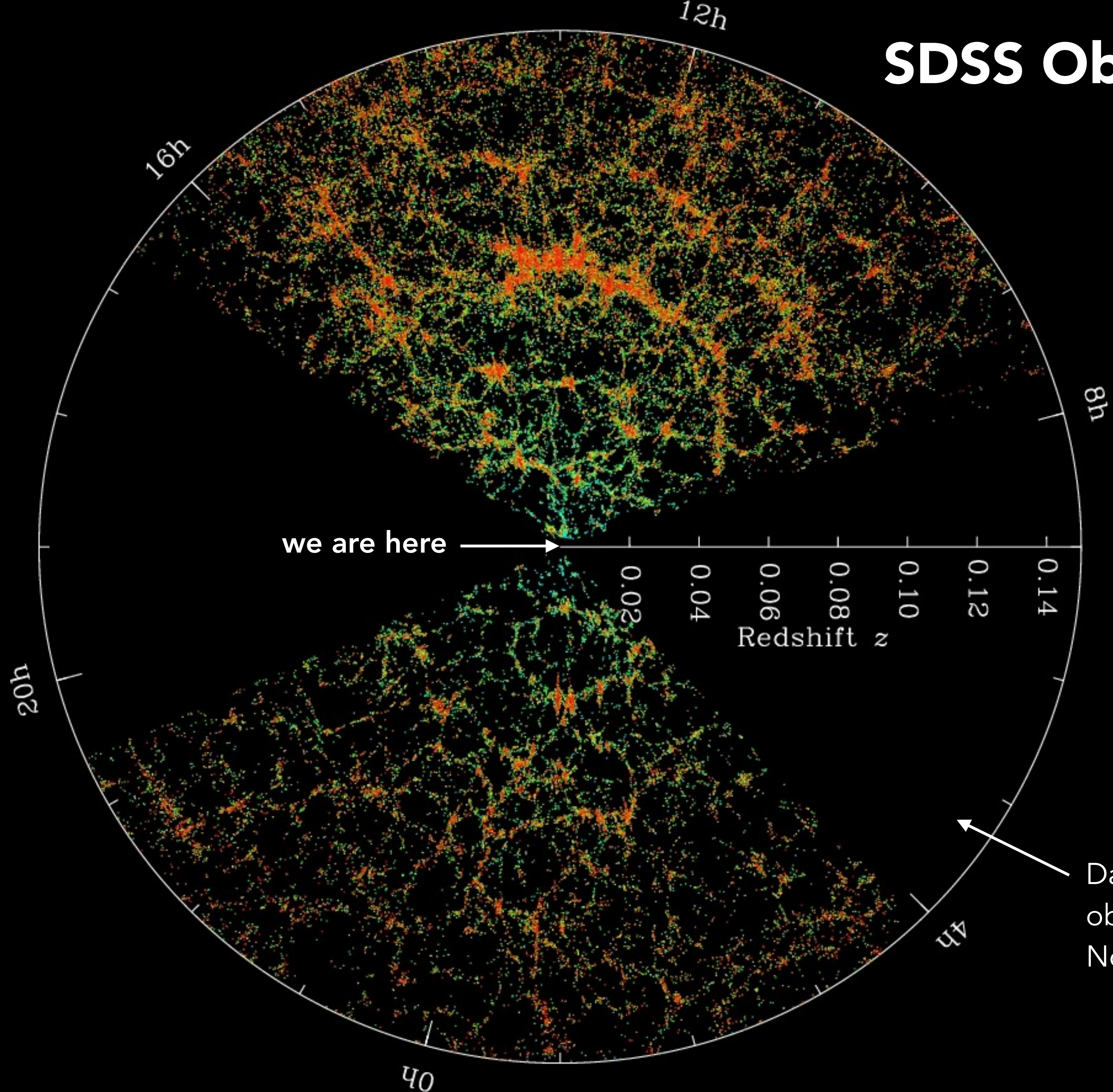
SDSS Collaboration (youtube)

Phases of SDSS



SDSS Collaboration

SDSS Observations

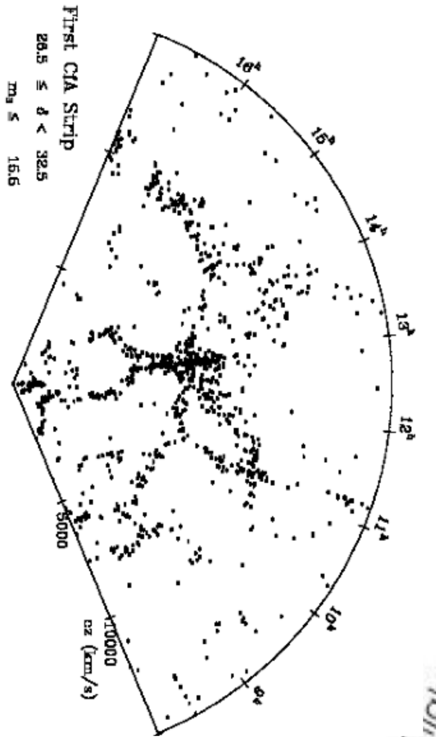


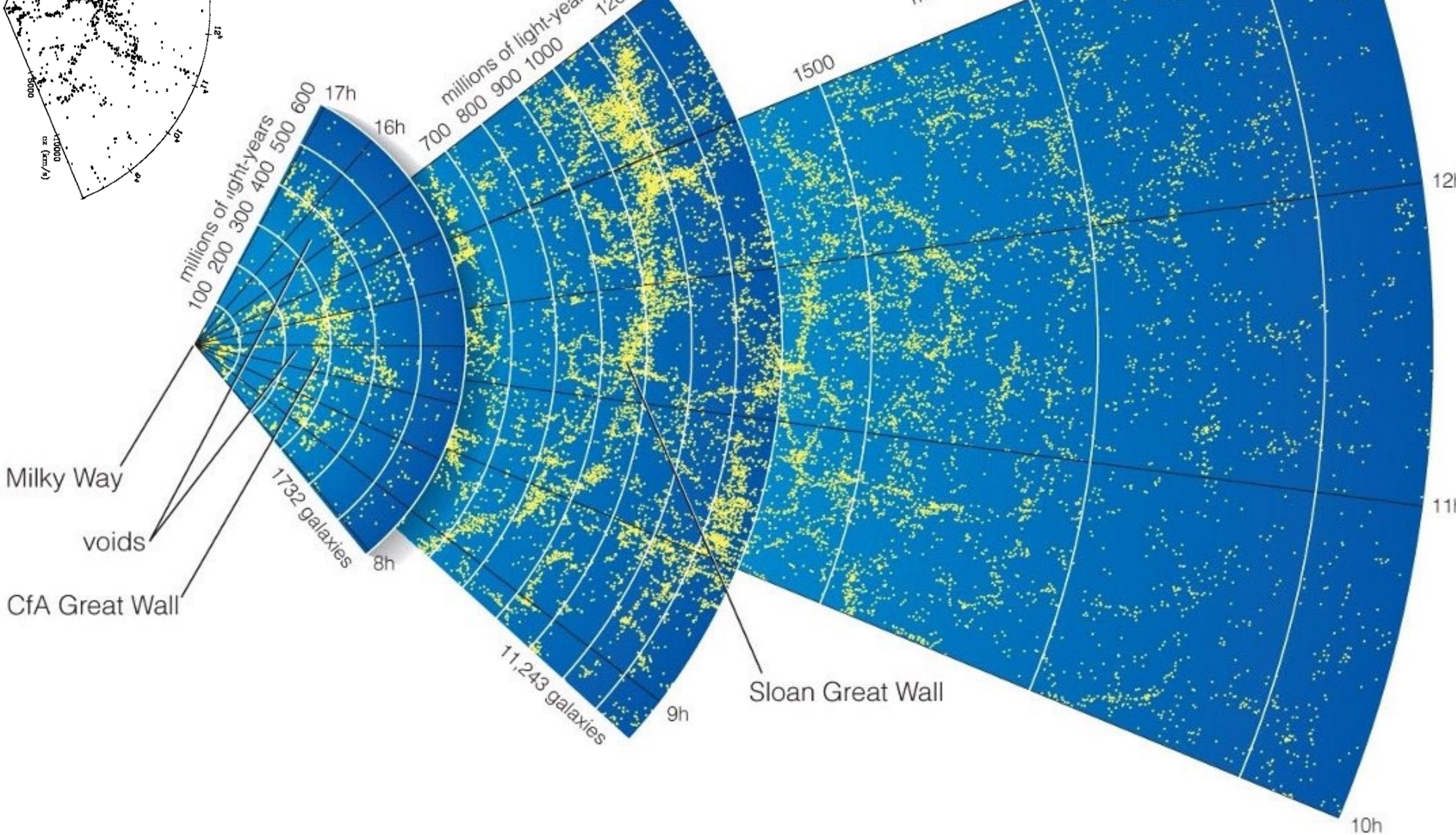
we are here

Dark wedges are not observable from Northern hemisphere

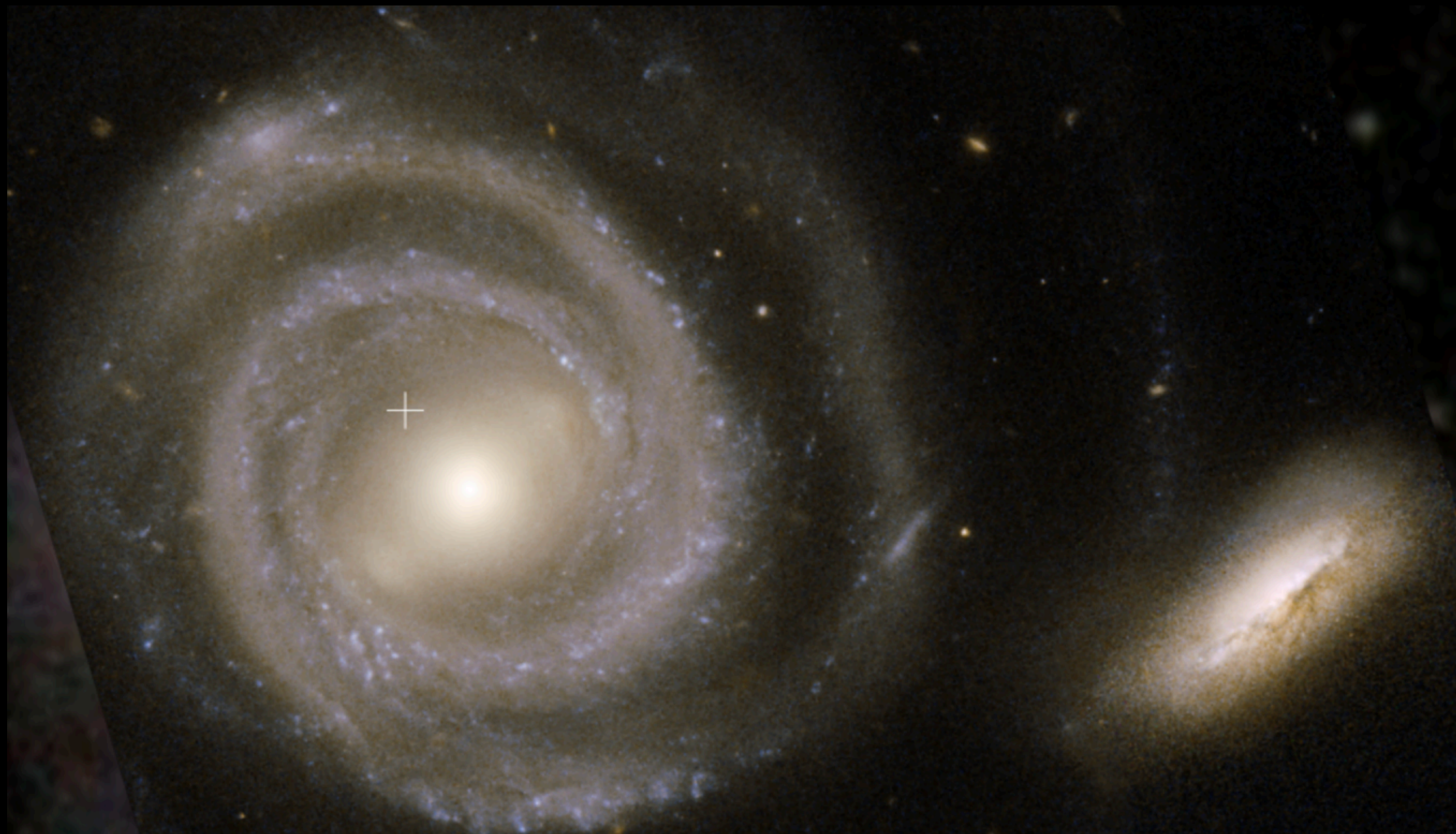
SDSS Collaboration

SDSS Observations





SDSS Collaboration

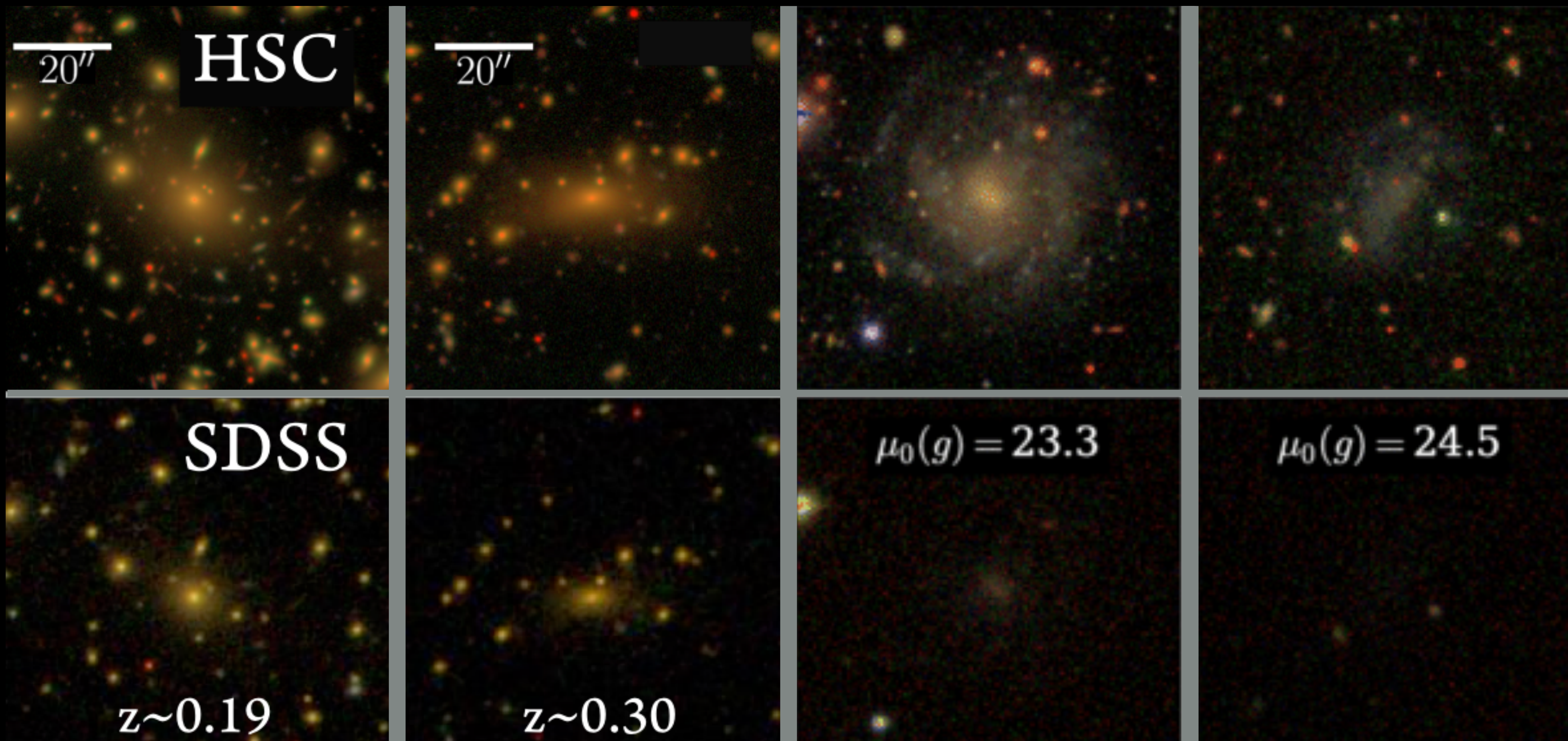


Hubble Space Telescope

NGC 5754

SDSS

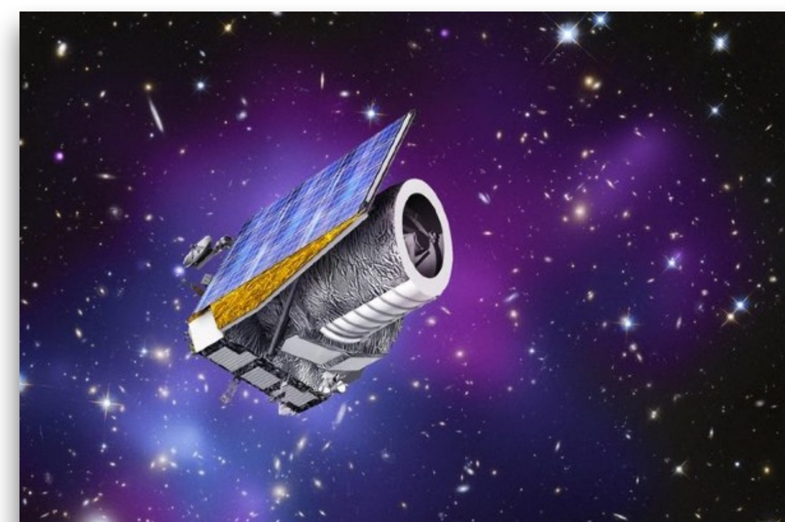
Current sky surveys



Images by Song Huang • Greco et al. 2017

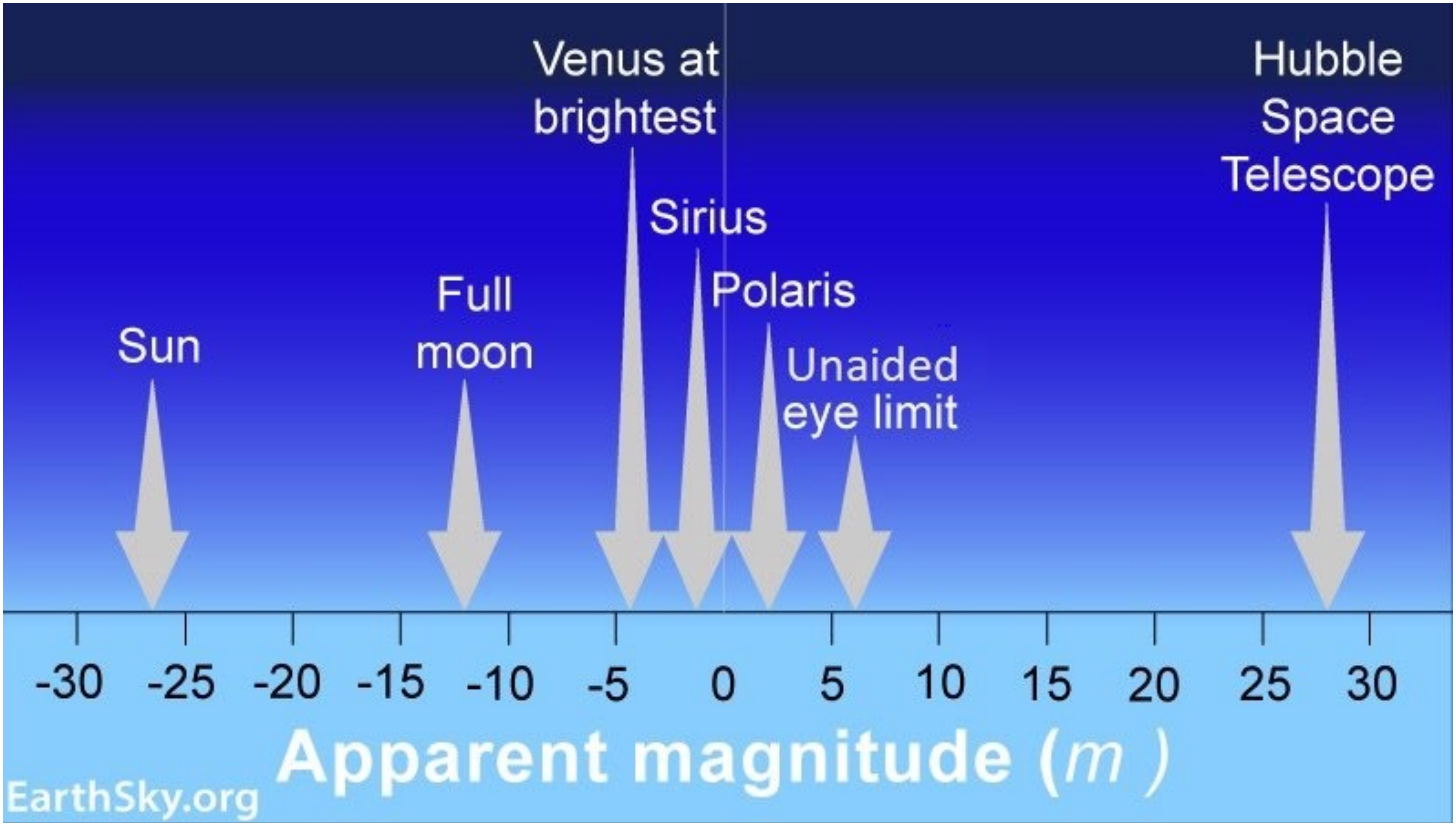
Future sky surveys

- SDSS observed about 1 million galaxies
- Newest surveys have covered
  300 million galaxies
- Euclid Satellite (ESA)
  - 1 billion galaxies
  - To redshift ~2 (10 billion years ago!)
- Vera Rubin Observatory / LSST
  - Will observe 20 billion galaxies
  - 20 TB / night
- Nancy Grace Roman Telescope
  - First wide-area survey from space

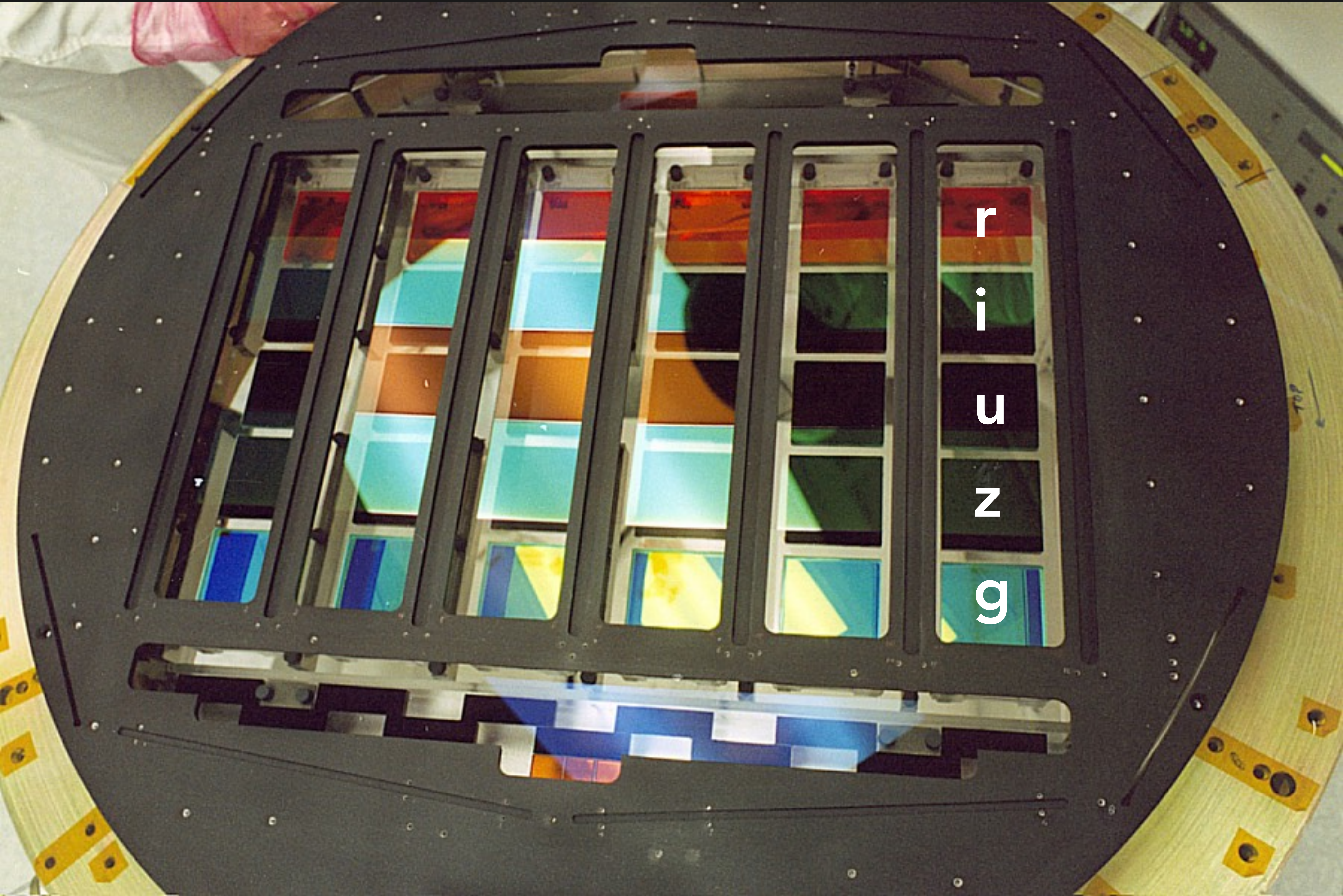


§2.2 • Magnitudes, spectra, and colors

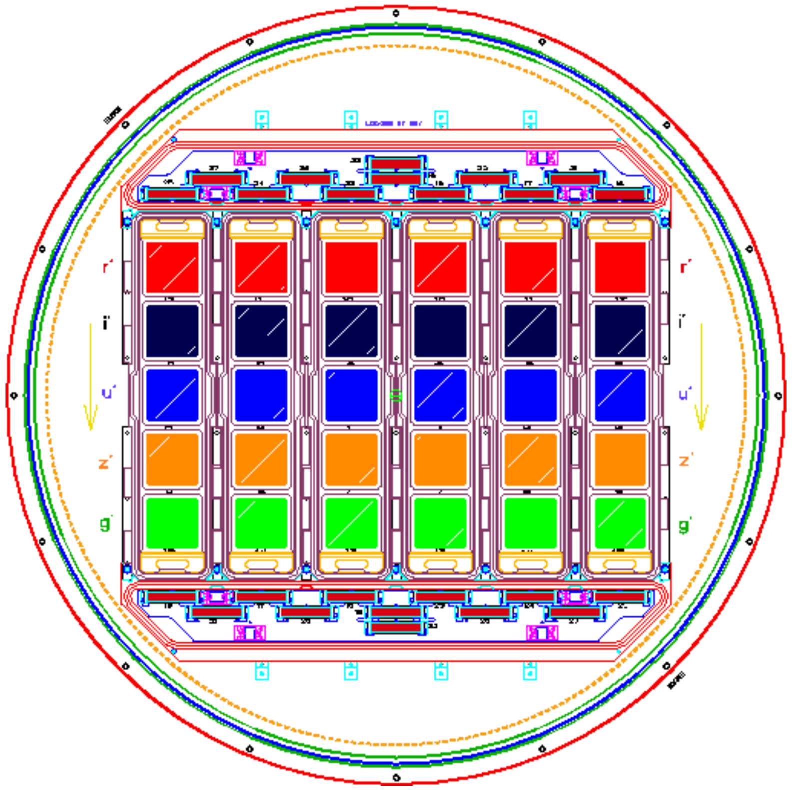
Apparent magnitude



SDSS imaging camera



SDSS filters



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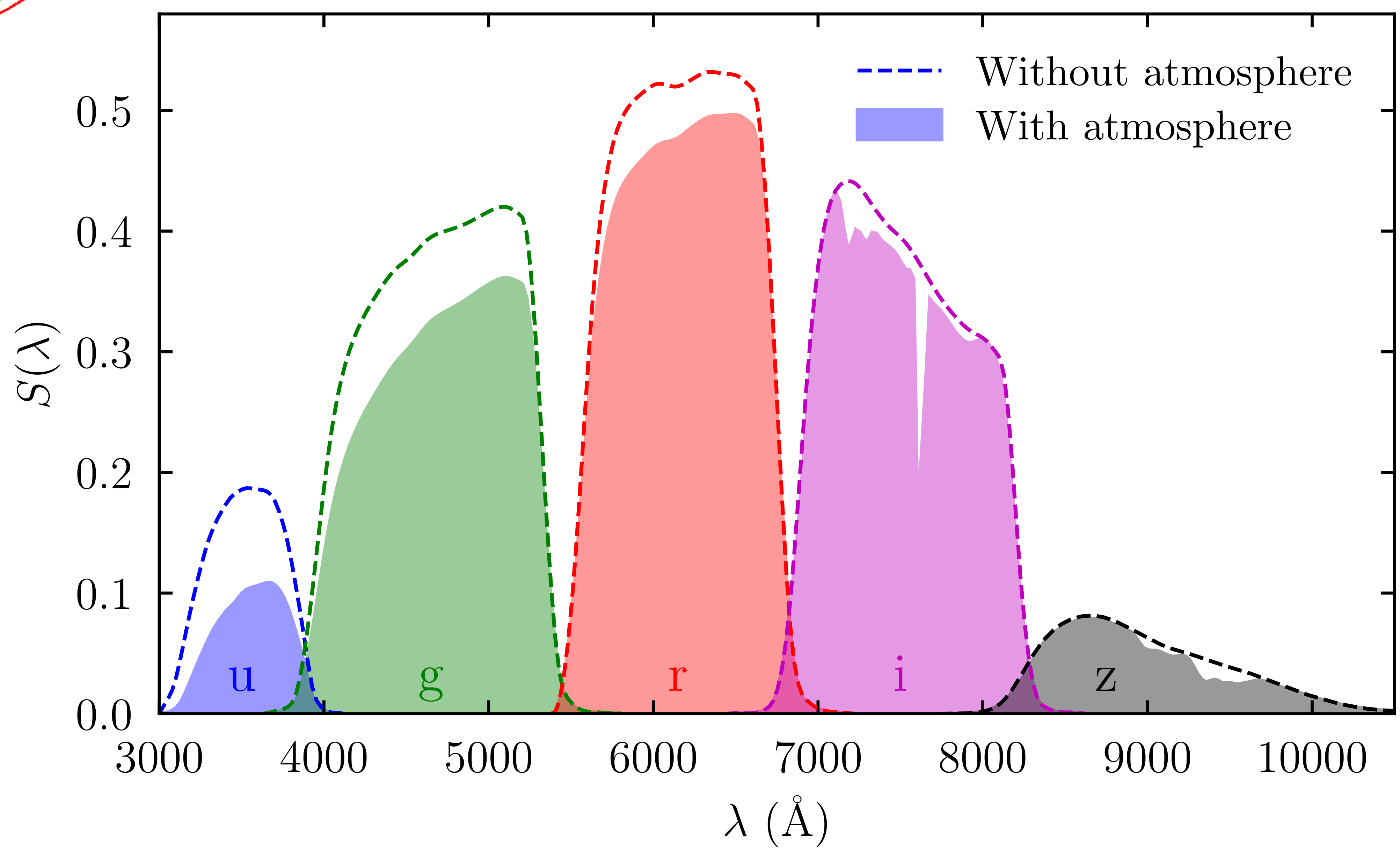
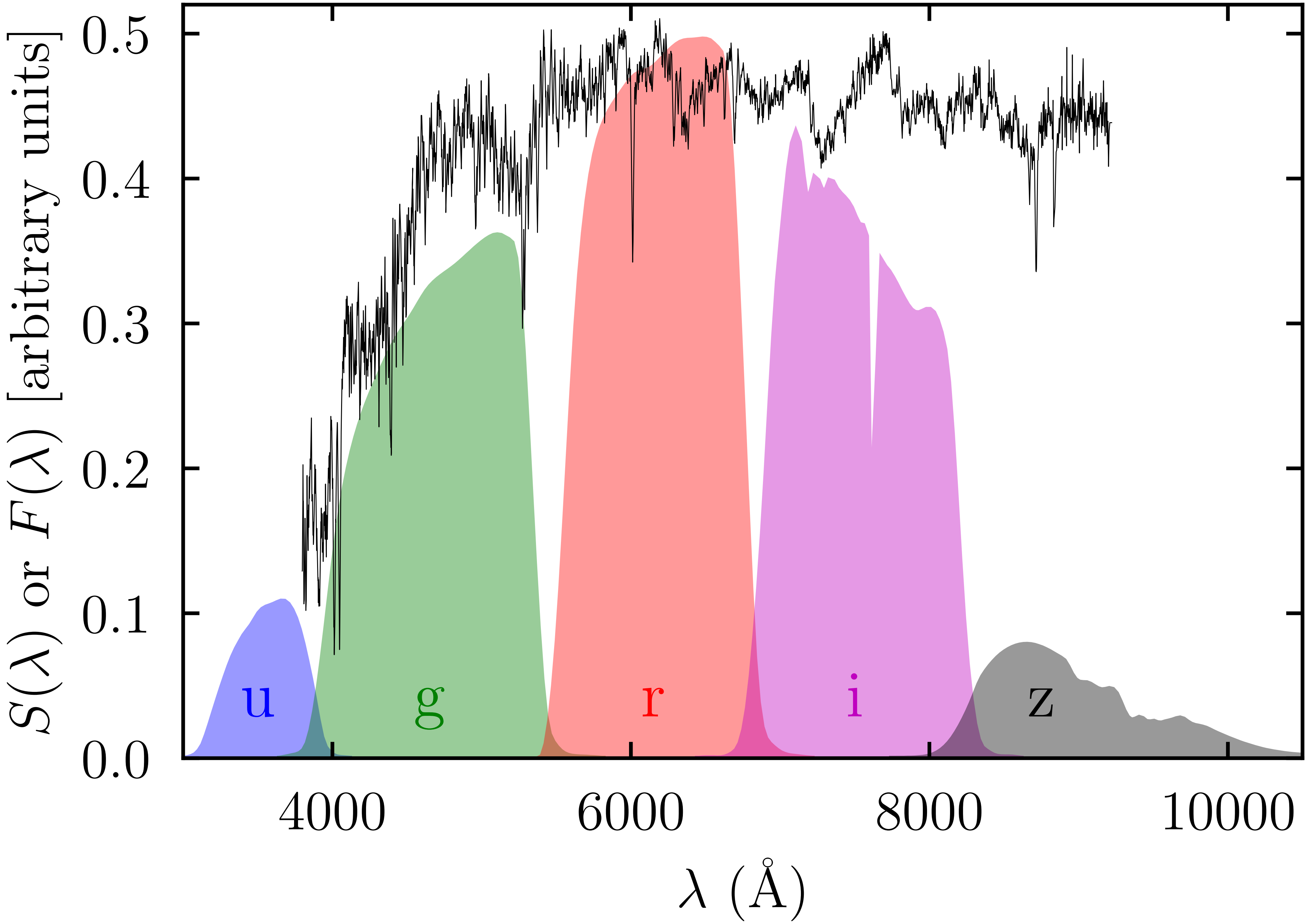
z
g

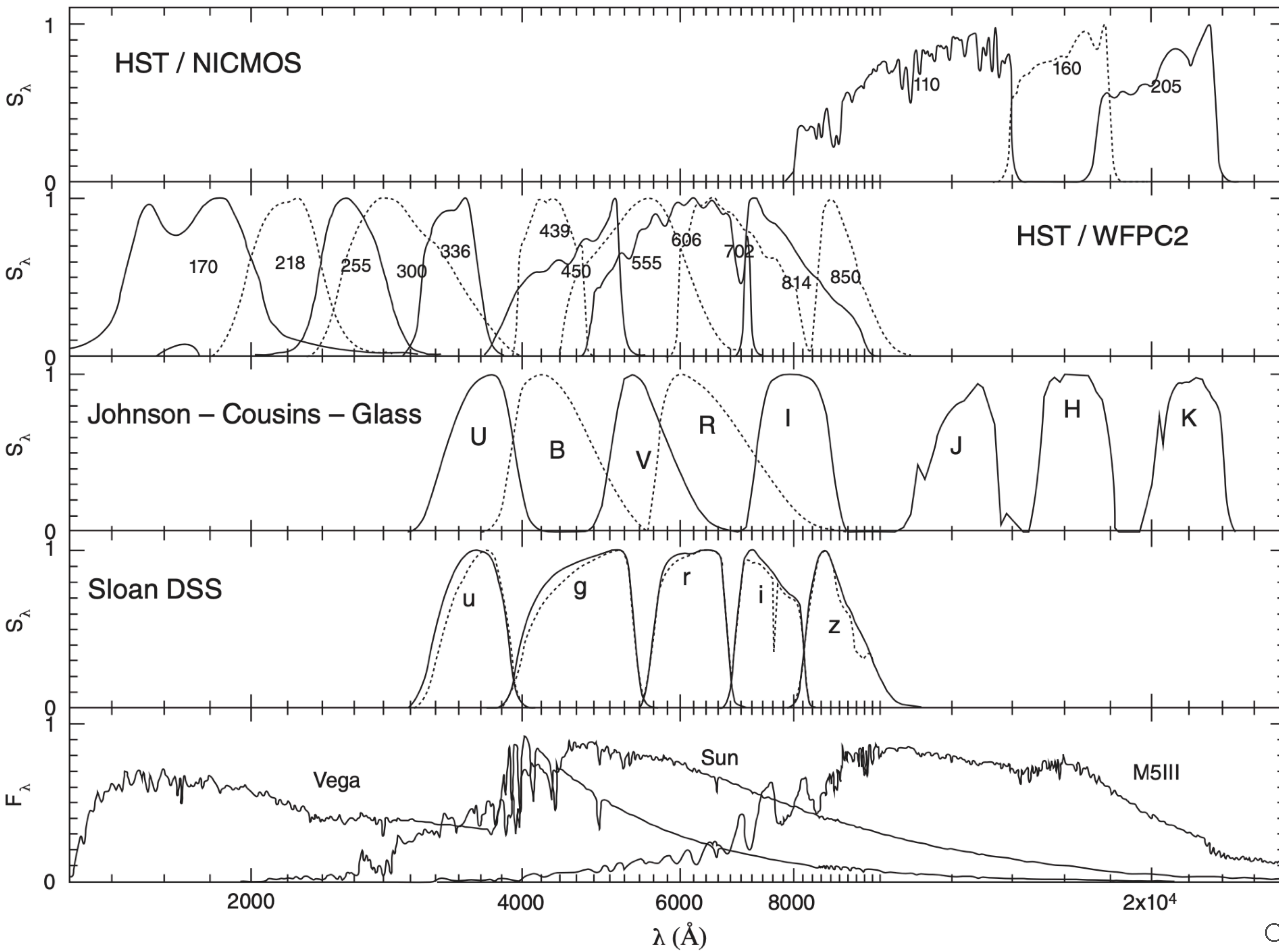


Spectra



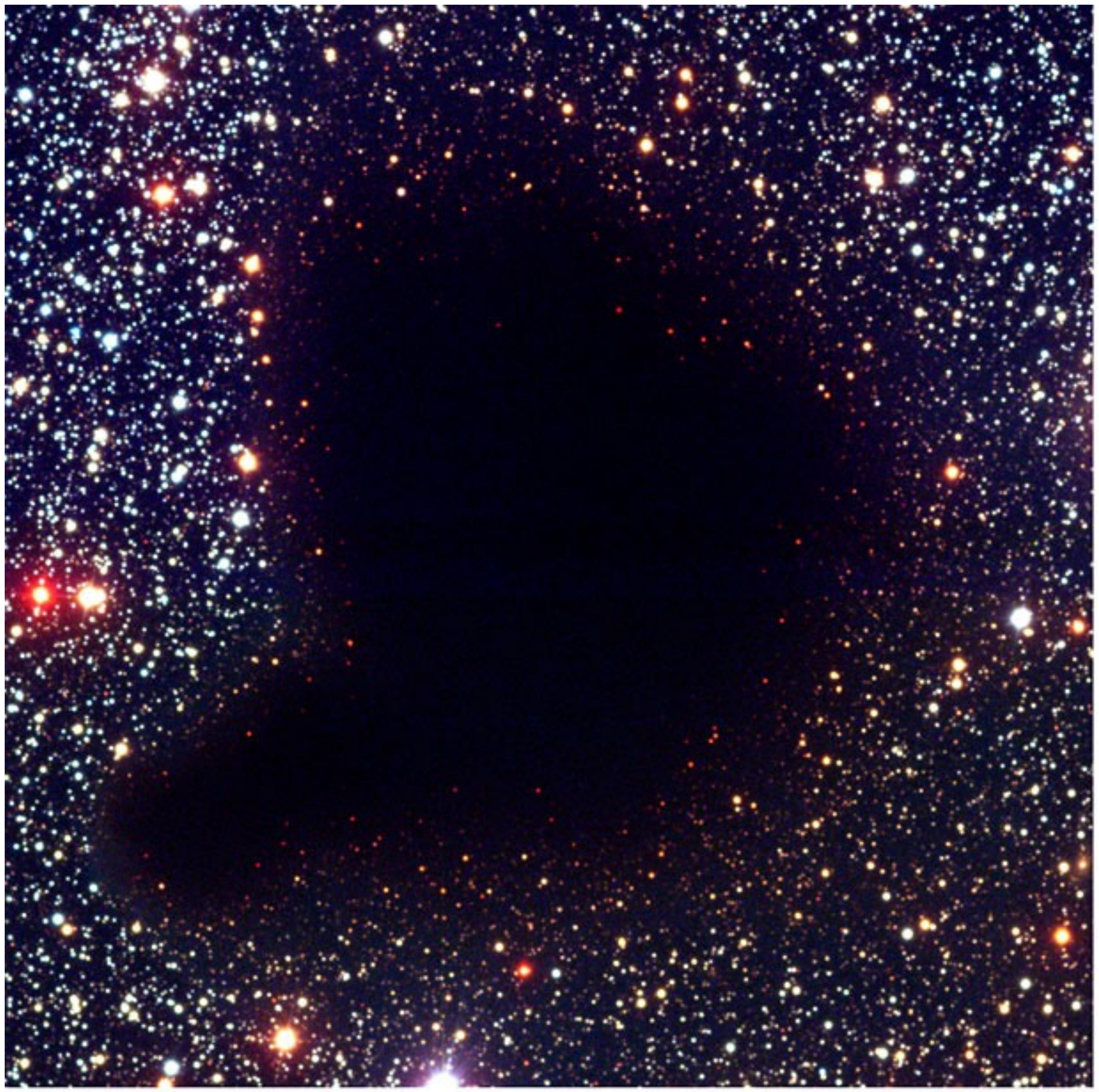
0.5
0.4
0.3
0.2
0.1
0.0
$S(\lambda)$ or $F(\lambda)$ [arbitrary units]
u
g
r
i
z
4000
6000
8000
10000
λ (Å)

Filter and magnitude systems

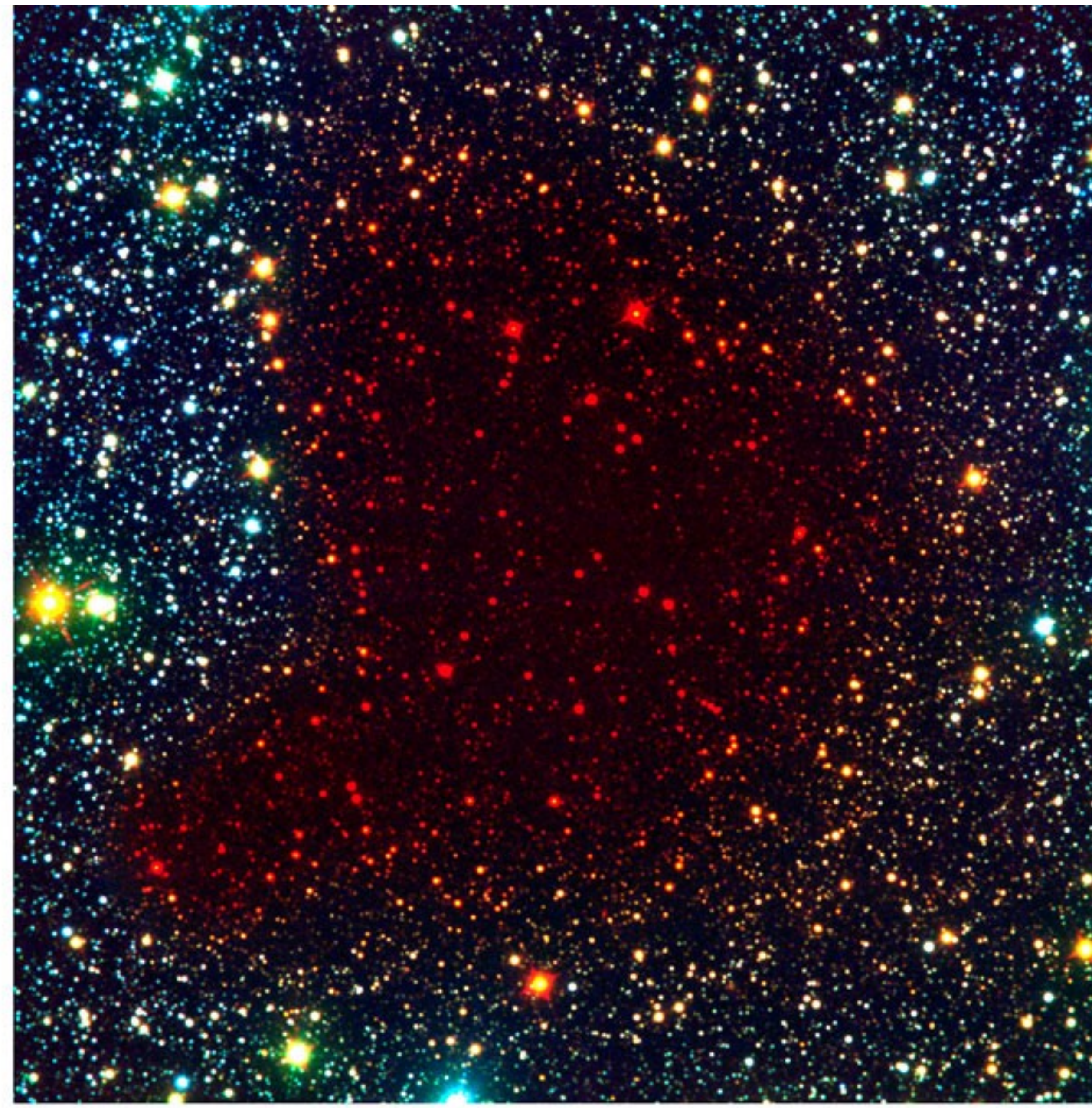


CFN §C.4

Dust absorption



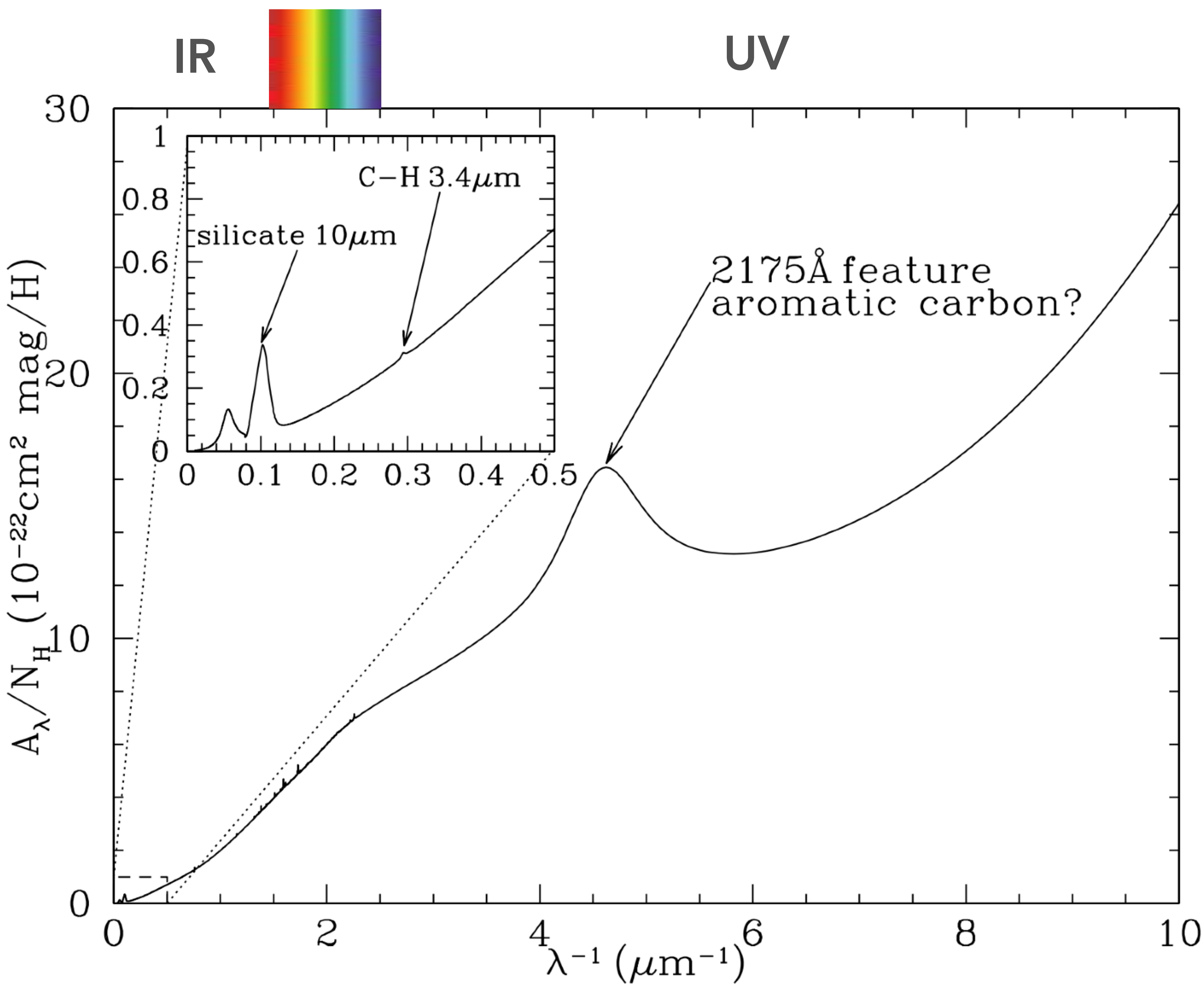
B, V, I



B, I, K

Barnard 68 molecular cloud

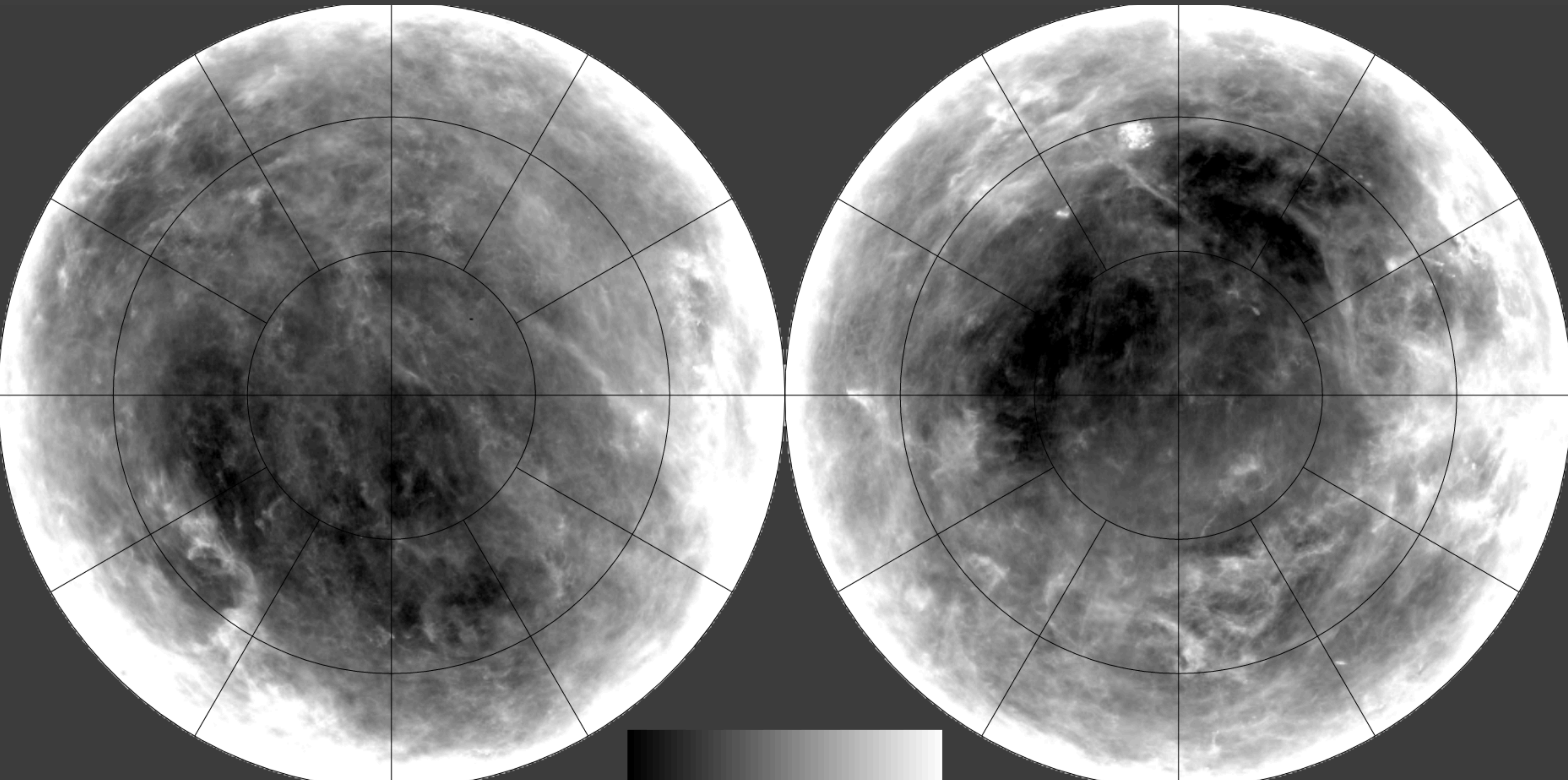
Dust extinction



Inverse wavelength!

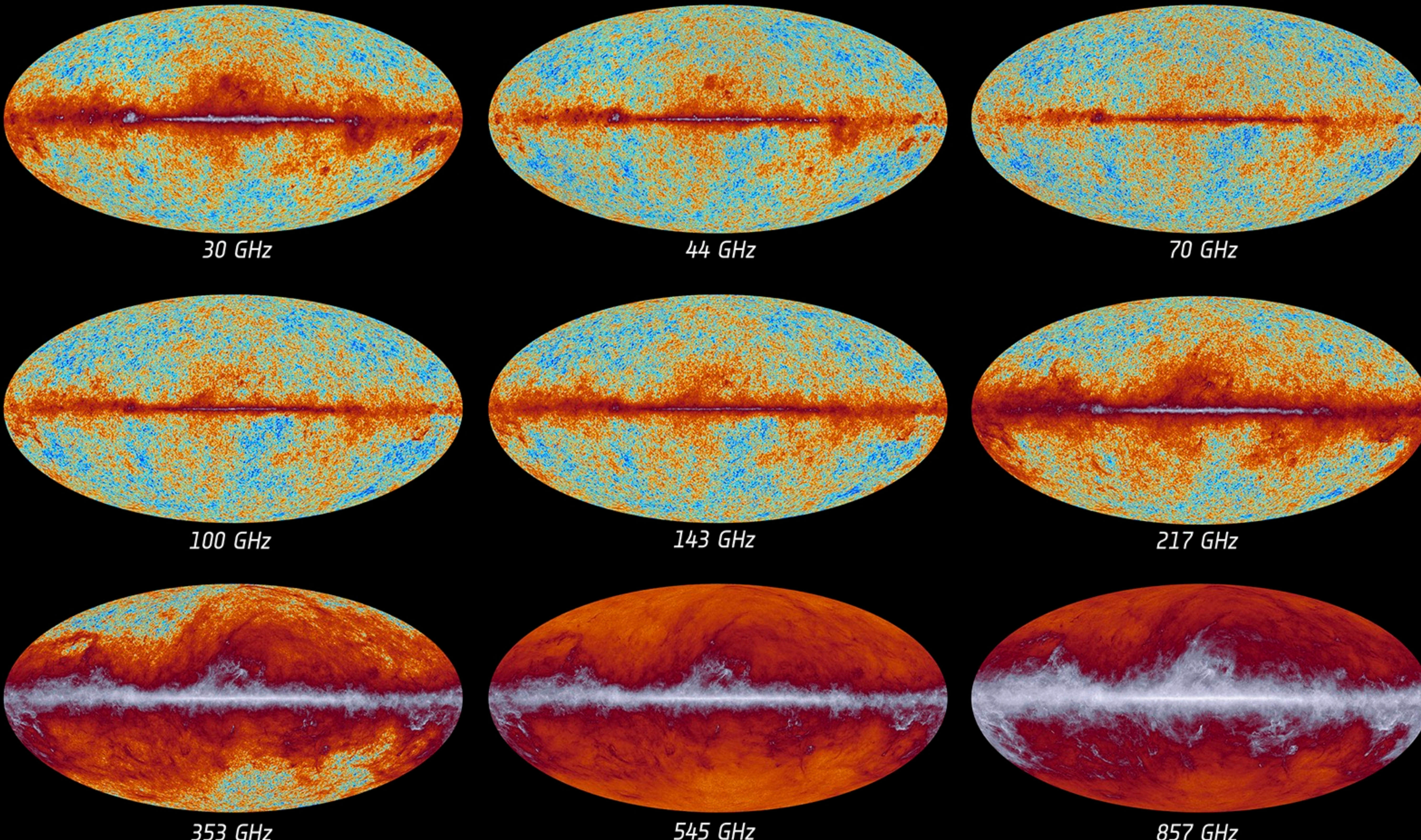
Draine §22.1

Galactic dust maps



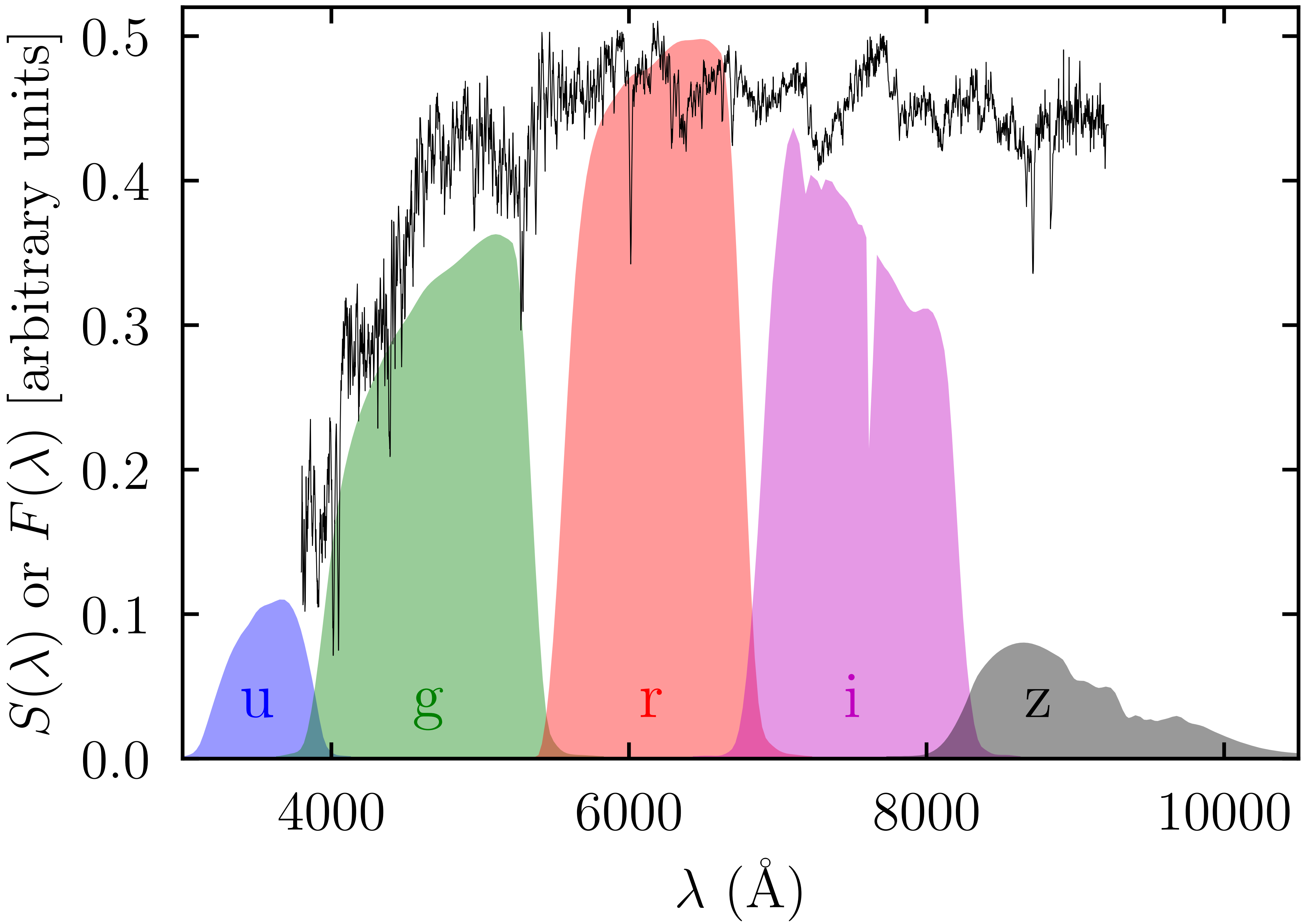
Schlegel et al. 1998

Planck (microwave, 3.5 - 100 mm)



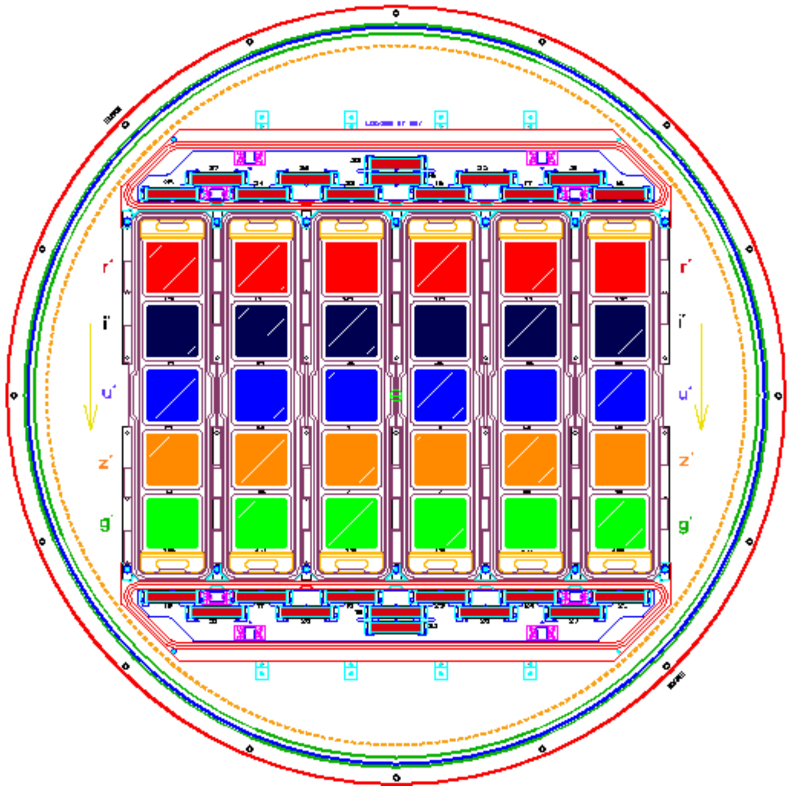
Planck collaboration

K-corrections



§2.3 • Surface brightness, size, and total flux

SDSS filters



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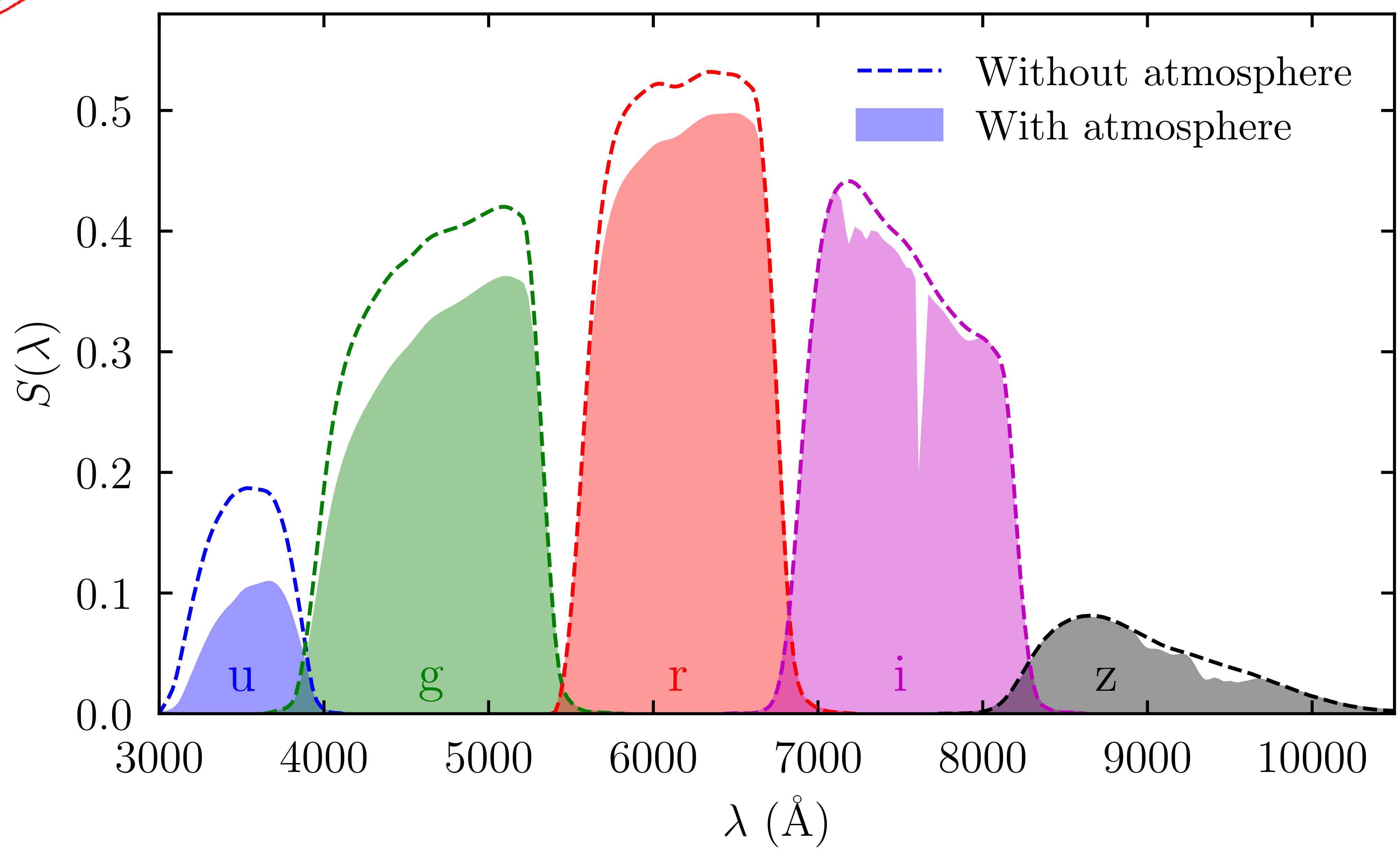
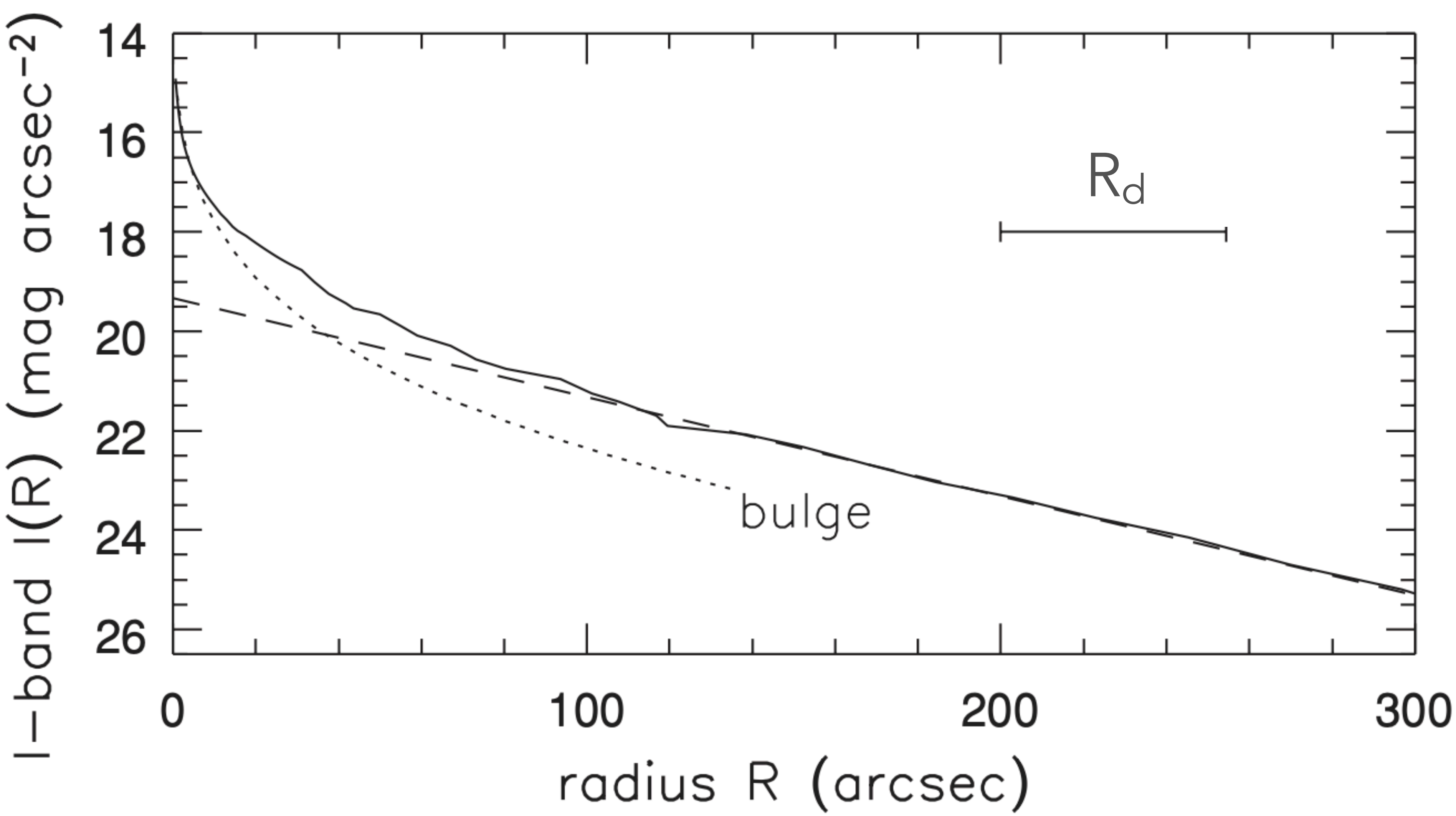
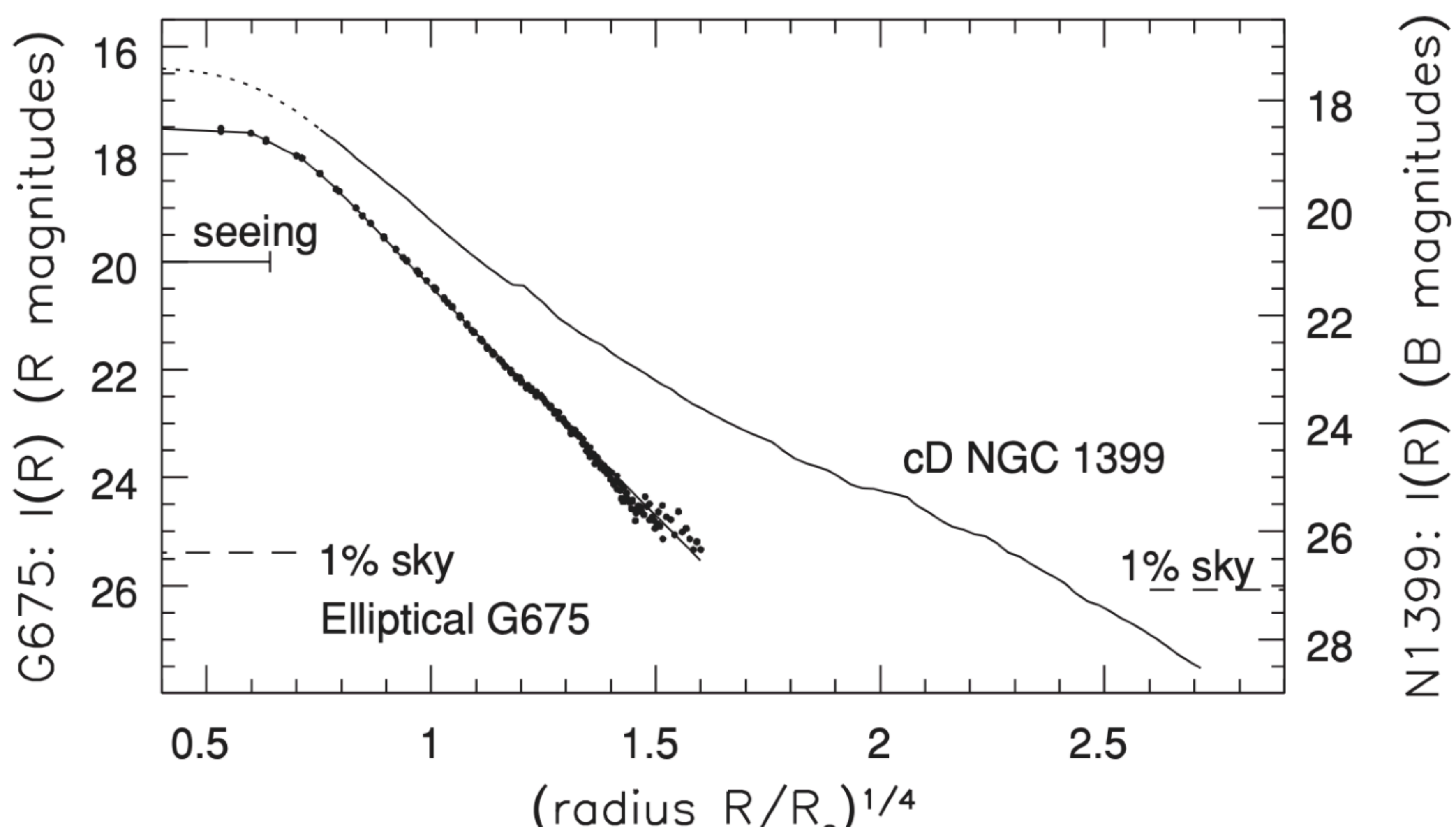


Exponential profile



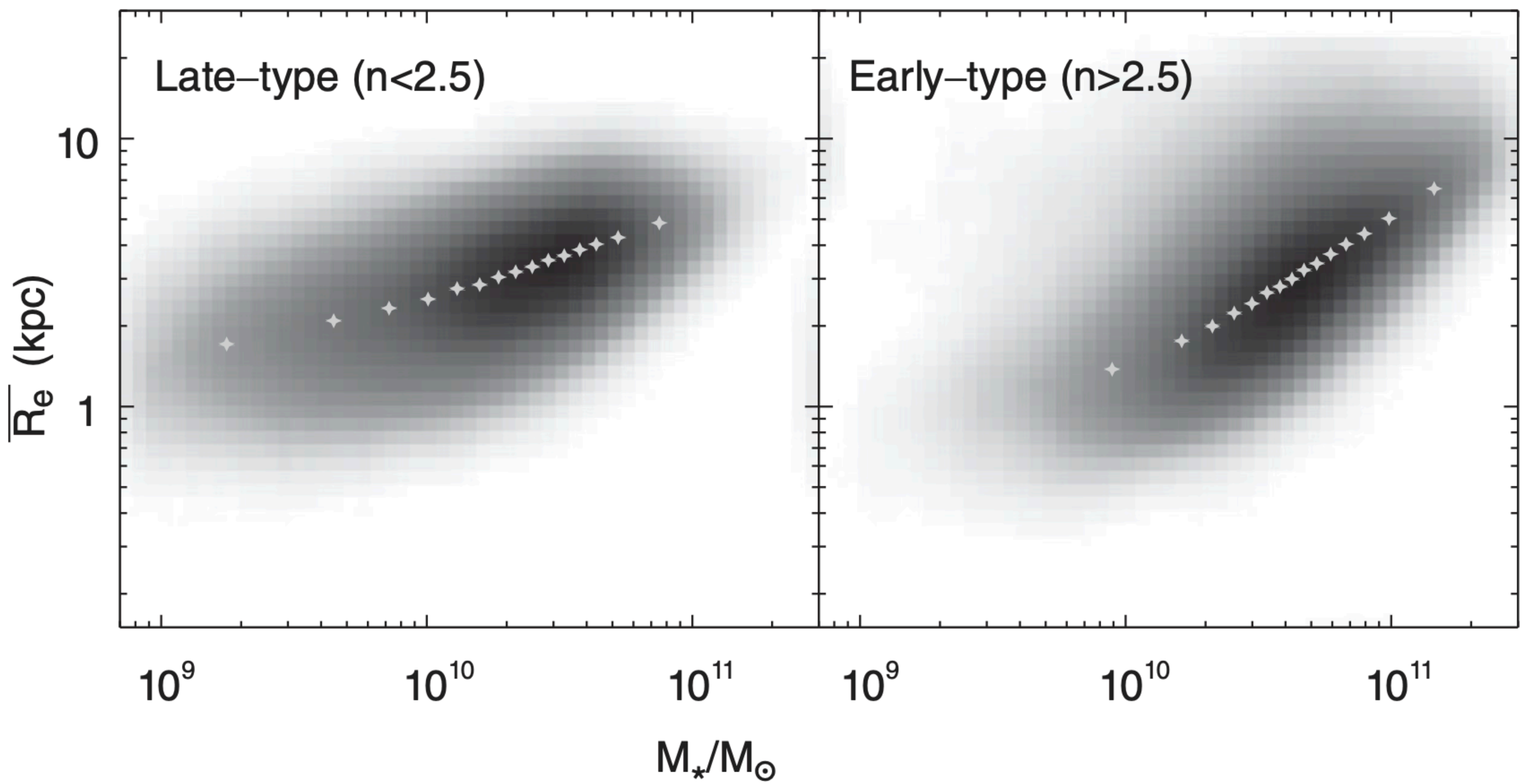
Sparke & Gallagher §5.1.2

de Vaucouleurs profile



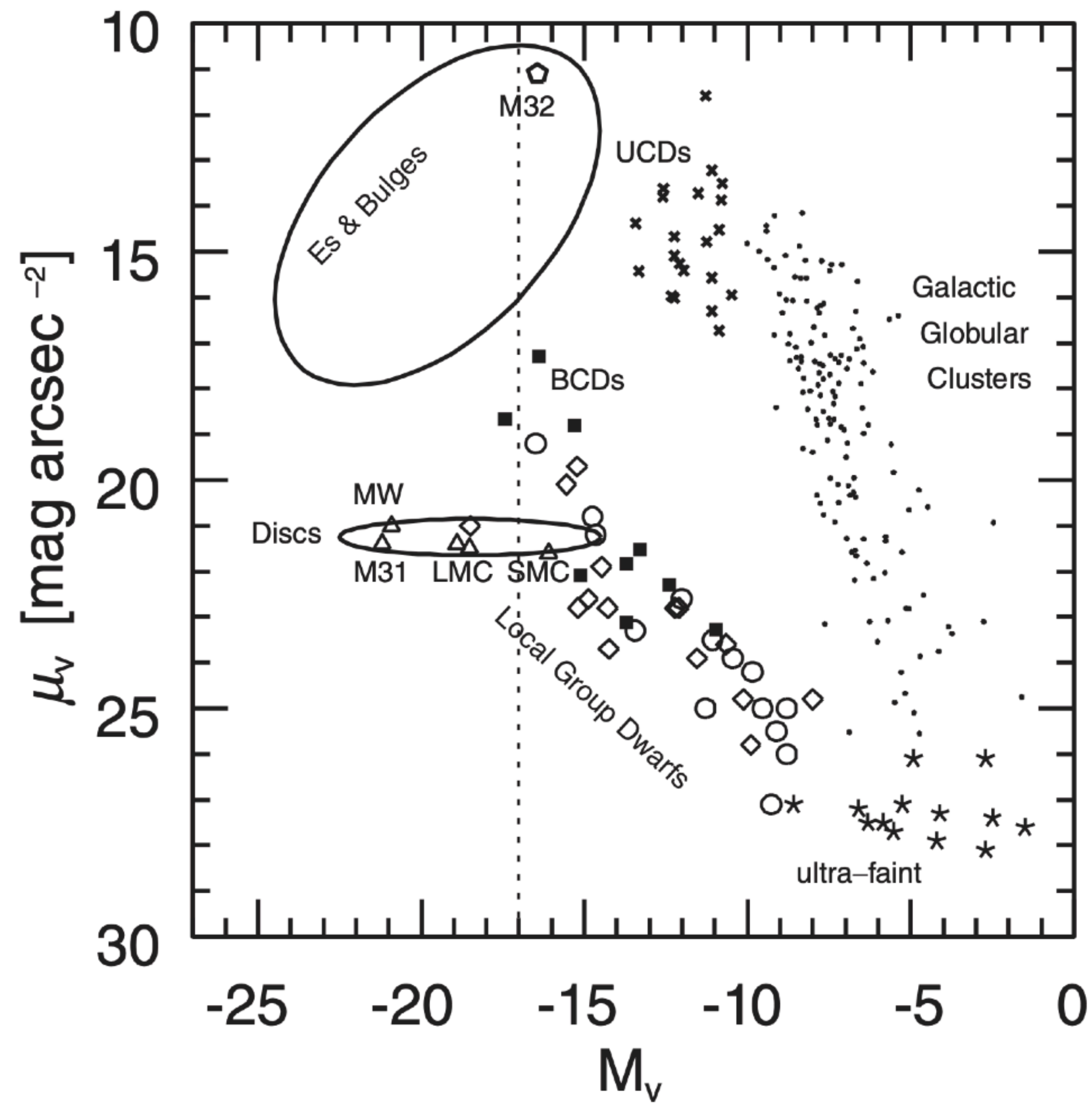
Sparke & Gallagher §6.1

Sizes



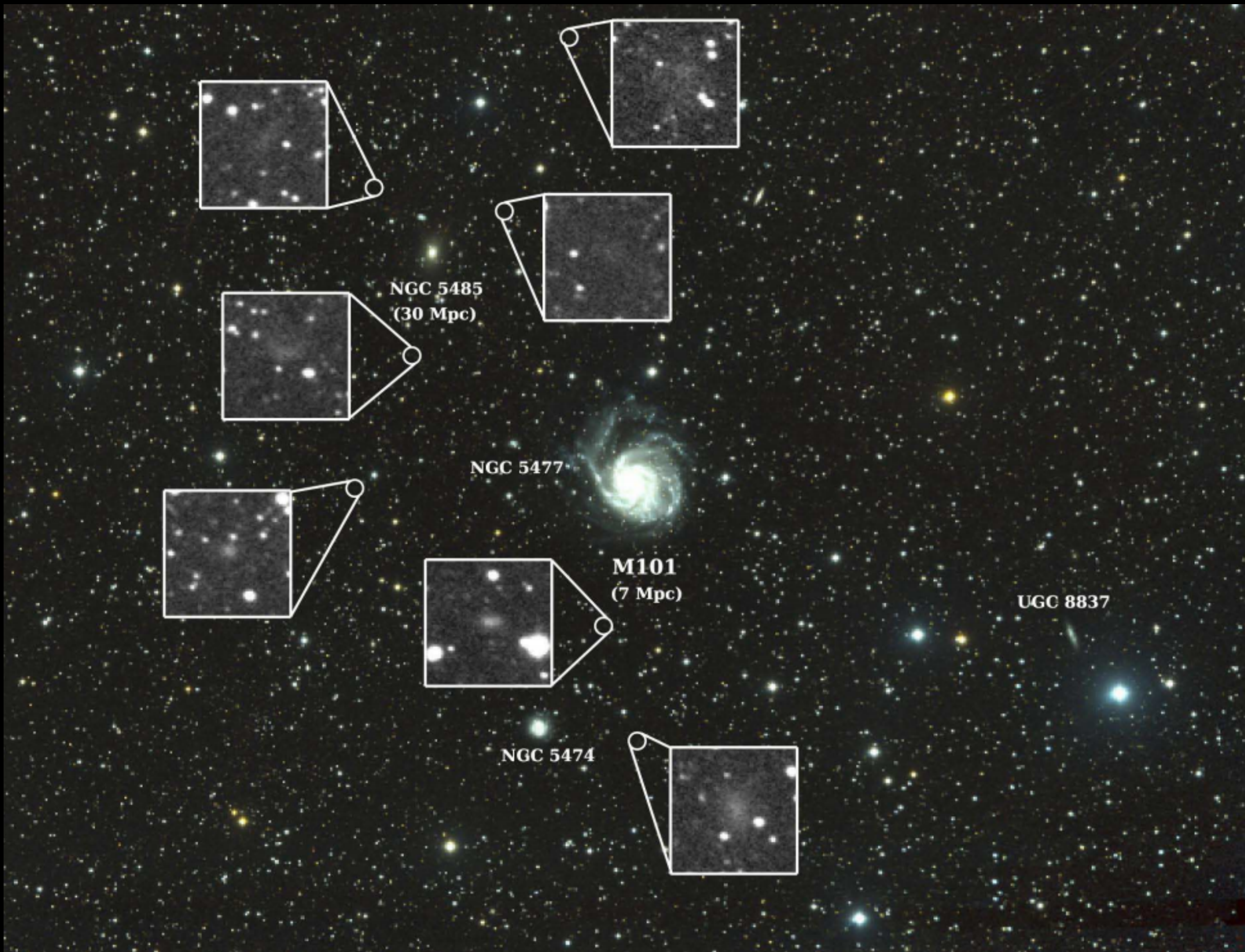
Cebrian & Trujillo 2014 • CFN §3.1.4

Central surface brightness vs. magnitude



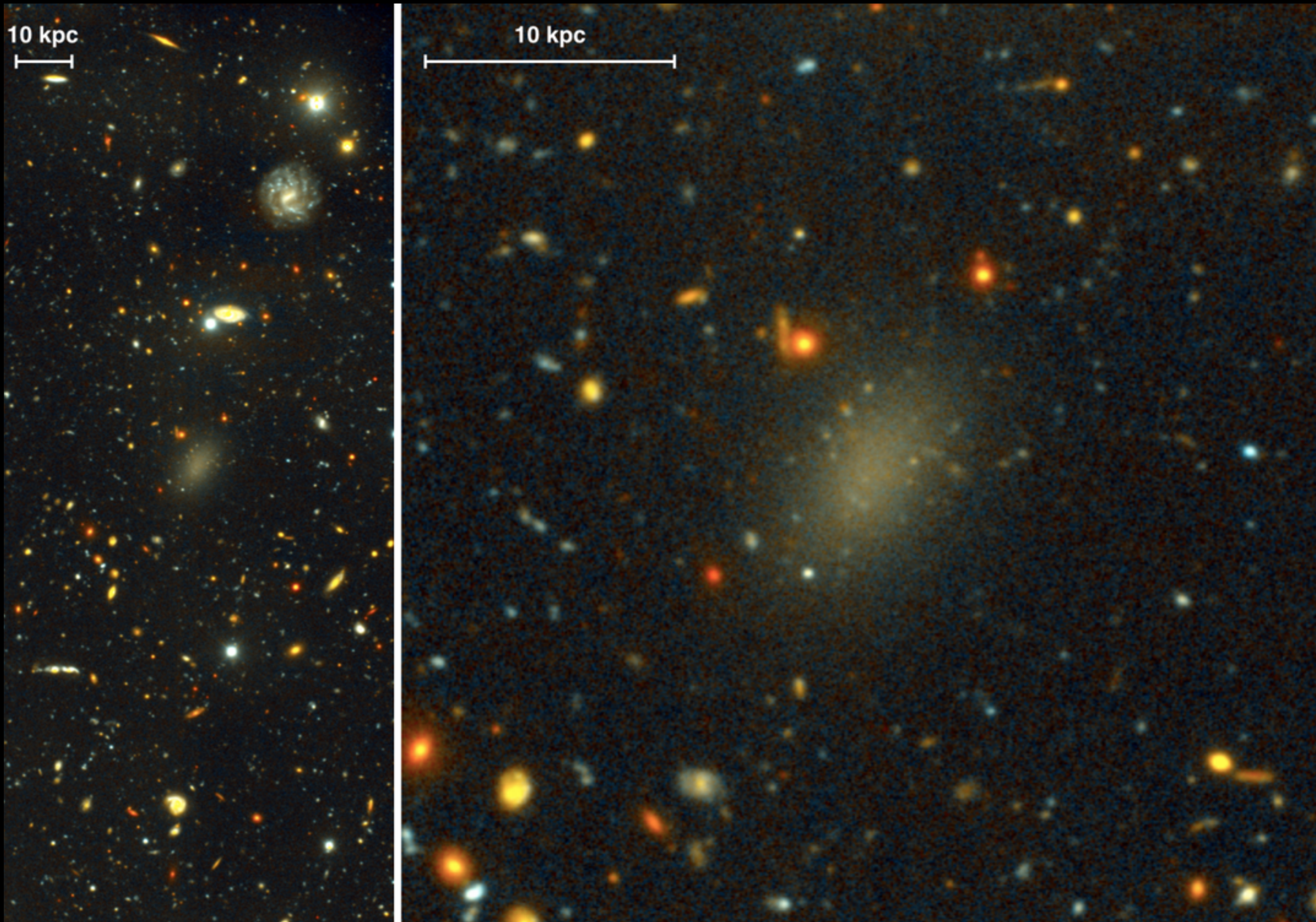
CFN §3.1.3

Low surface brightness galaxies

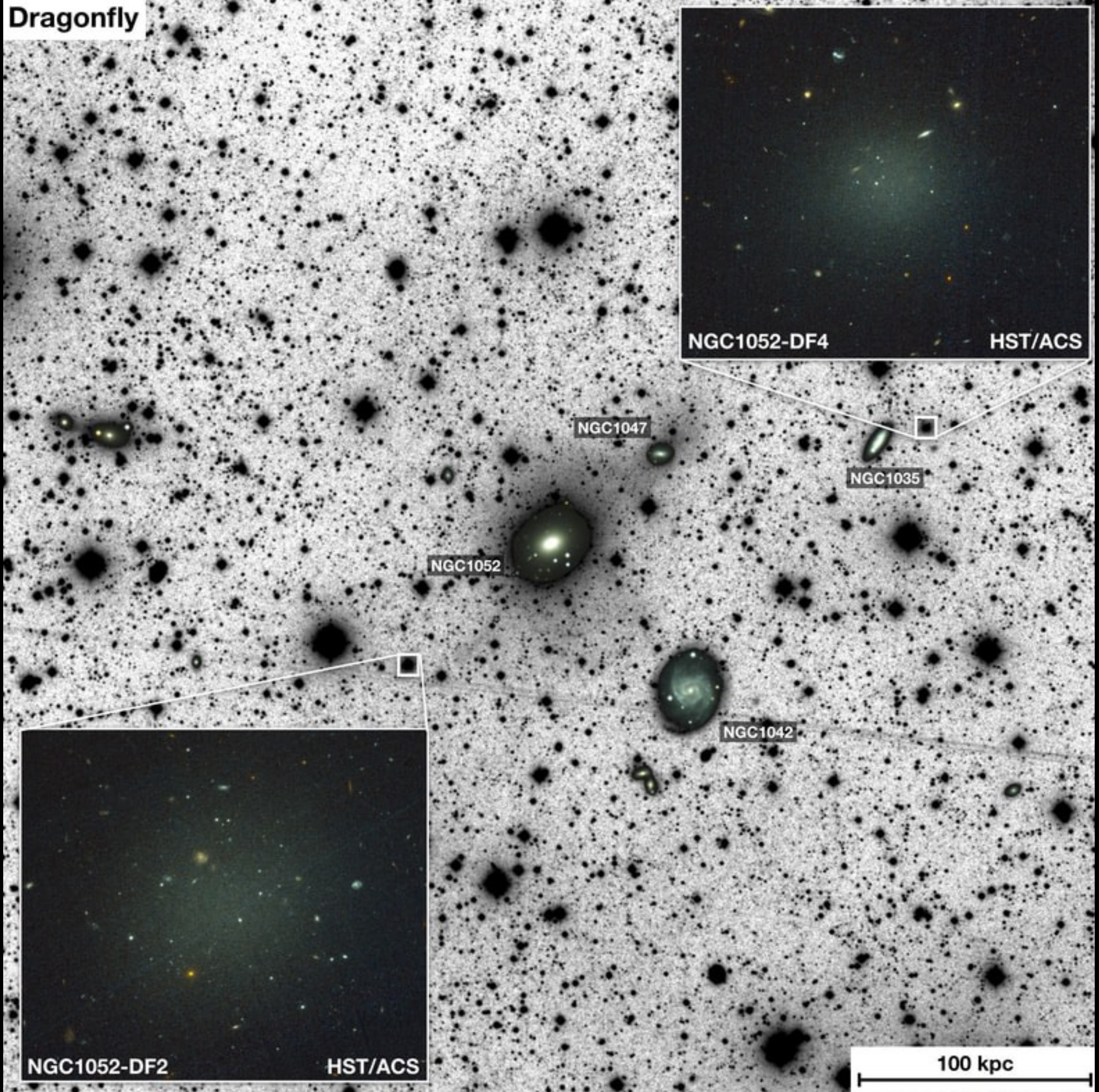


Dragonfly Collaboration

Low surface brightness galaxies



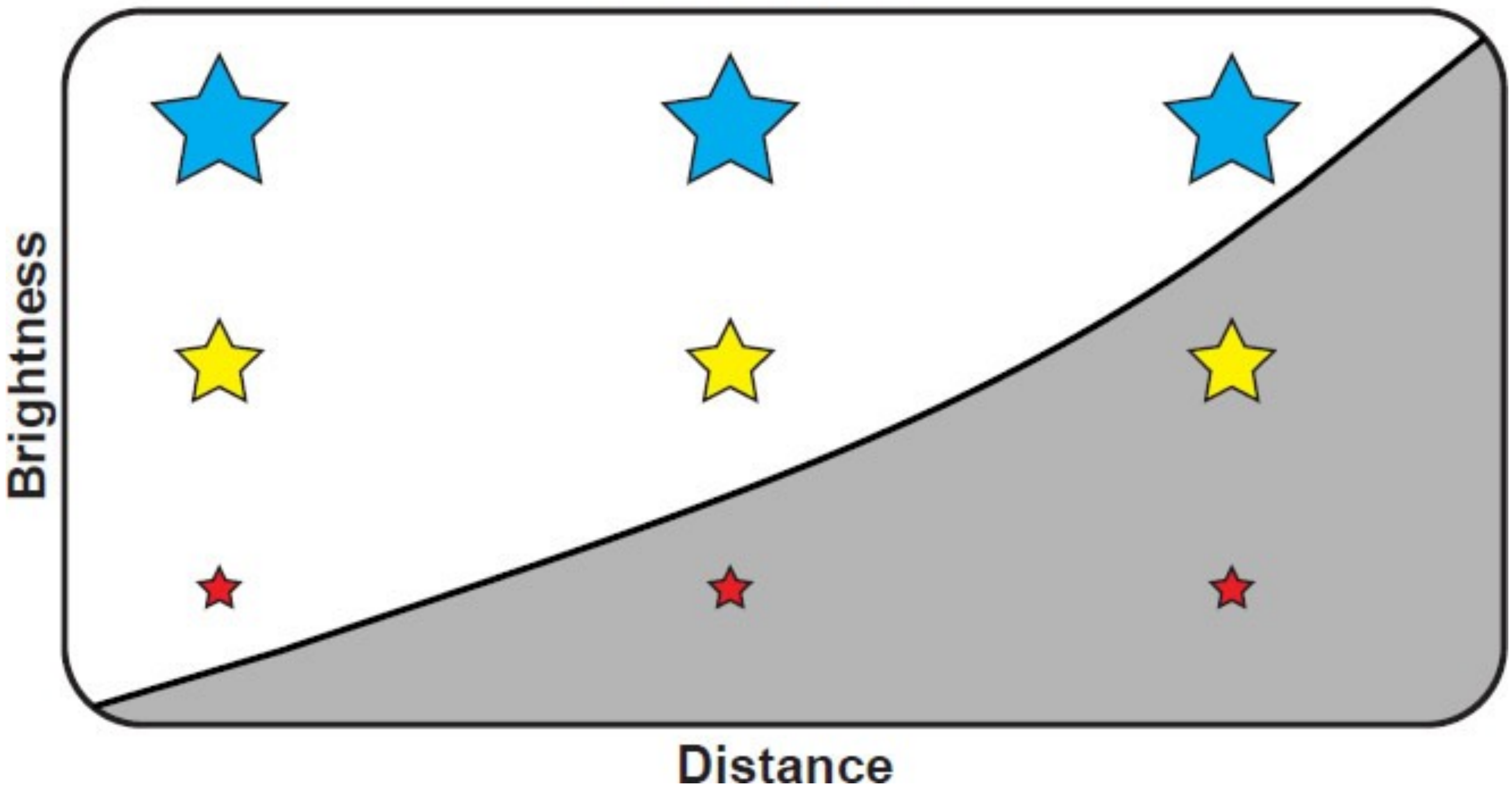
Dragonfly Collaboration



Dragonfly Collaboration

§2.4 • Luminosity functions

Malmquist bias



Malmquist 1922

Schechter function

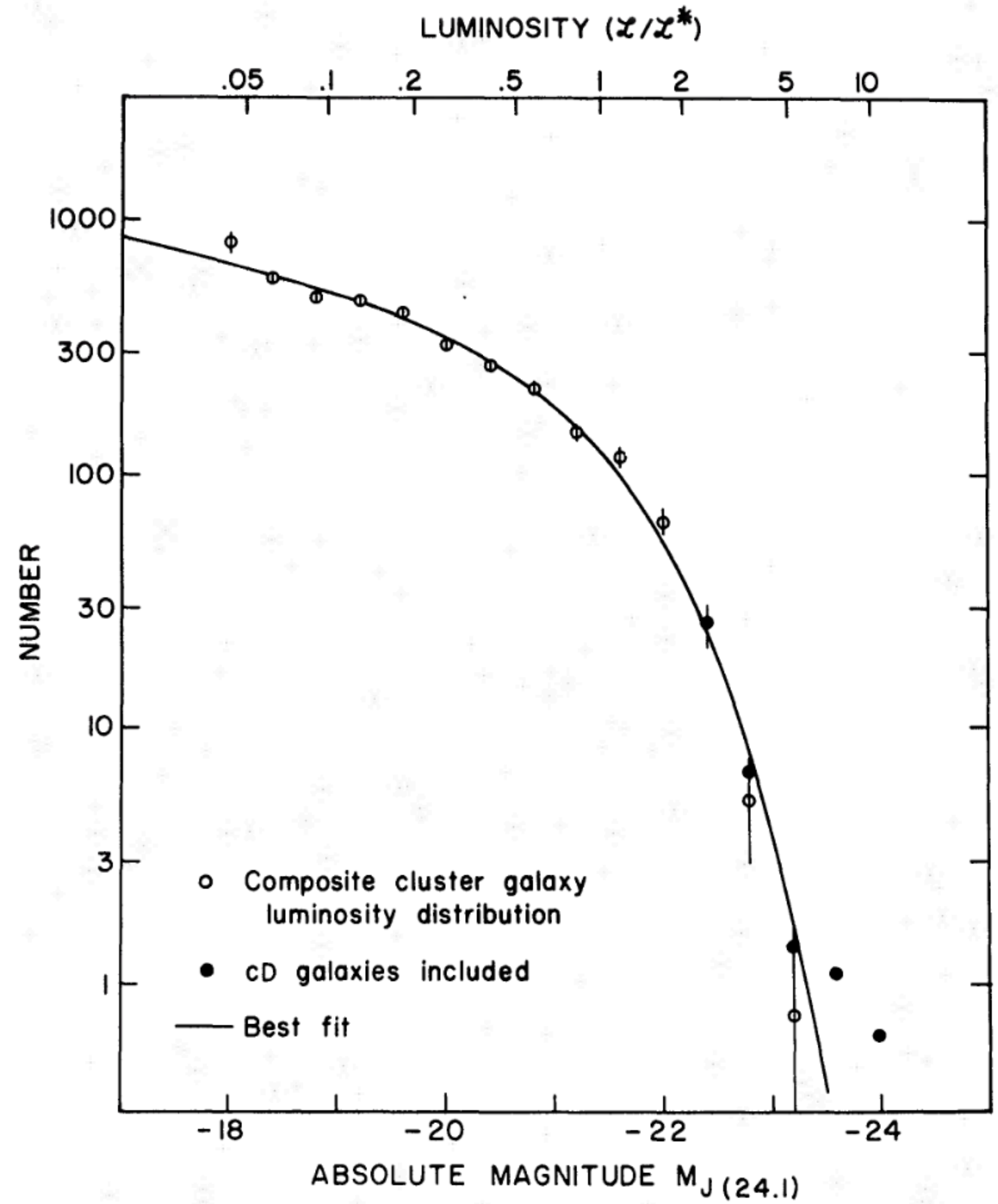


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Schechter 1976

§2.5 • Morphology

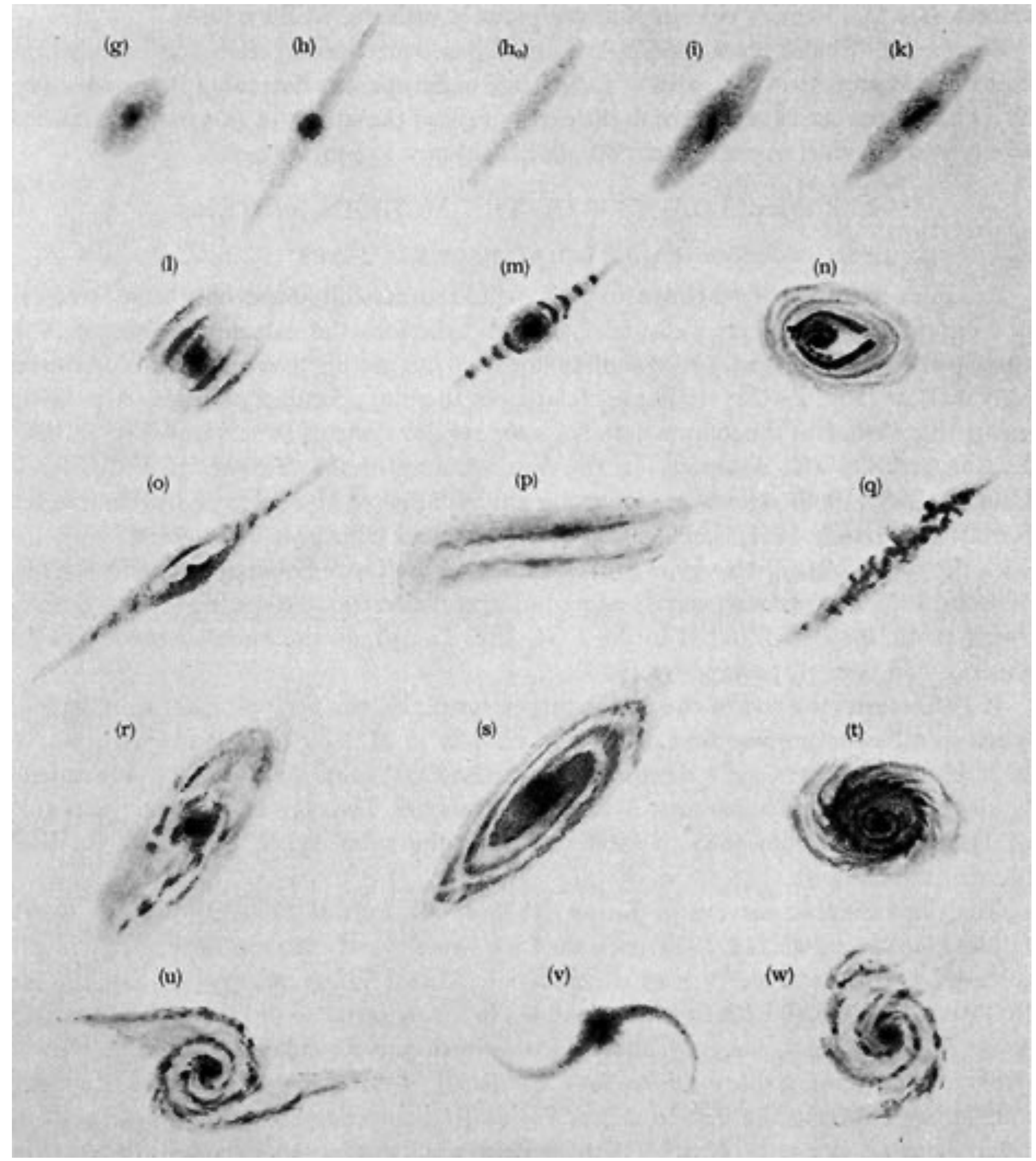
§2.5.1 • The “Hubble fork” classification system

Whirlpool Galaxy (M51 a/b)

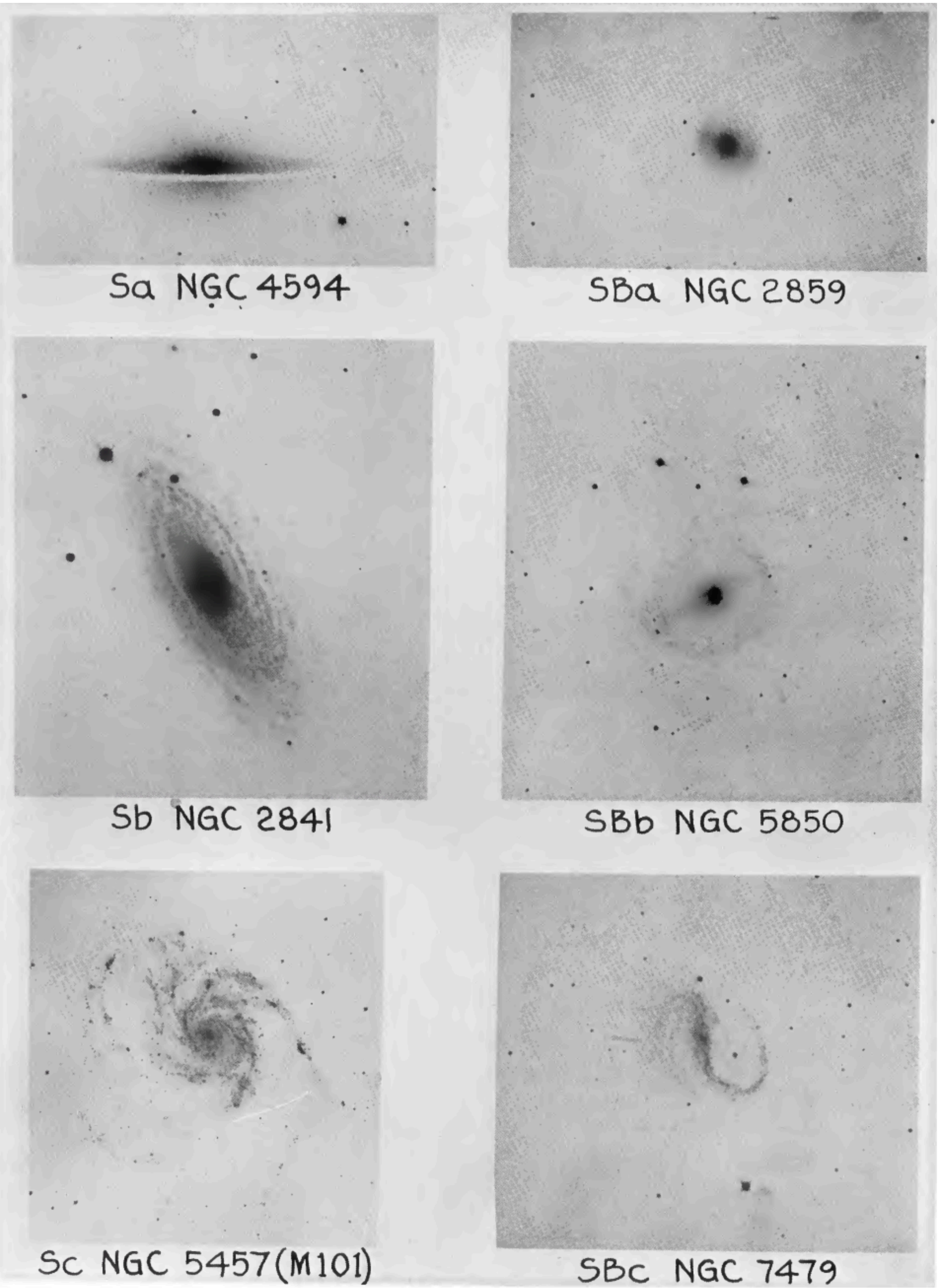
Drawing by Lord Rosse (1845)

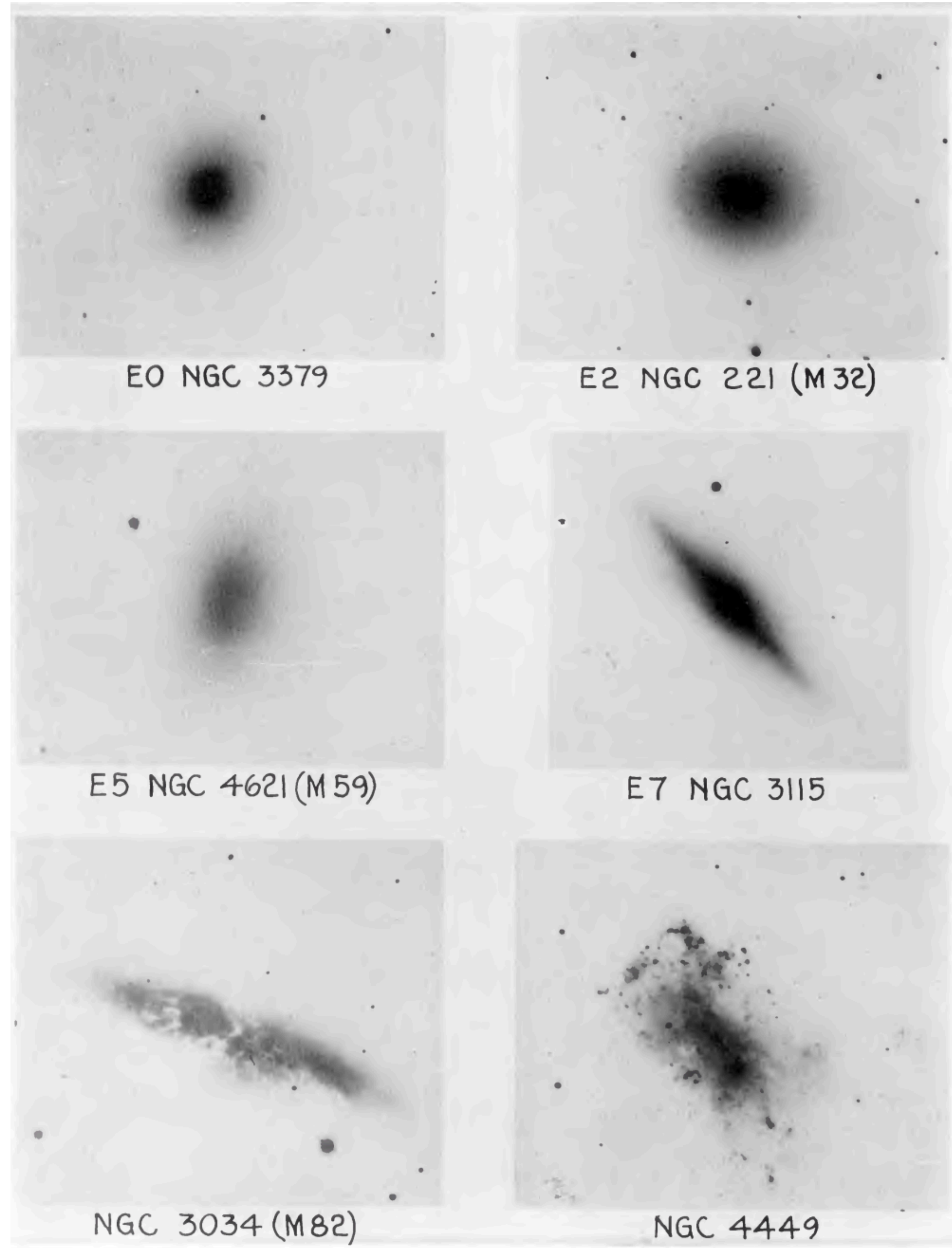
Morphological classification

- Classification system by Wolf 1908
- Ordered from amorphous to clear shapes



Images from Hubble (1926)





“From a study of all available photographs with large reflectors, it is found that the characteristic features of non-galactic nebulae are rotational symmetry about dominating nuclei. About 2.5% are irregular, lacking both these features, and form a homogeneous class of which the Magellanic Clouds are the most conspicuous members. The regular nebulae fall into a progressive sequence ranging from globular masses of unresolved nebulosity through lenticular forms to the open spirals with arms swarming with stars. This purely observational sequence conforms very closely to Jeans’ theory of the origin and evolution of spirals.”

Edwin Hubble (1926)

Slide inspired by notes by Andrey Kravtsov

Hubble Fork

- Classification scheme for galaxies according to **shape**, prominence of **spiral arms**, and **bars**
  - Ellipticals: No spiral arms, round to elliptical shape
  - Spirals: Have central bulge, halo, disk, and spiral arms
  - Barred Spirals: Spirals that have a "bar" running through their centers
  - Irregular: Lower mass galaxies, often satellites of more massive galaxies

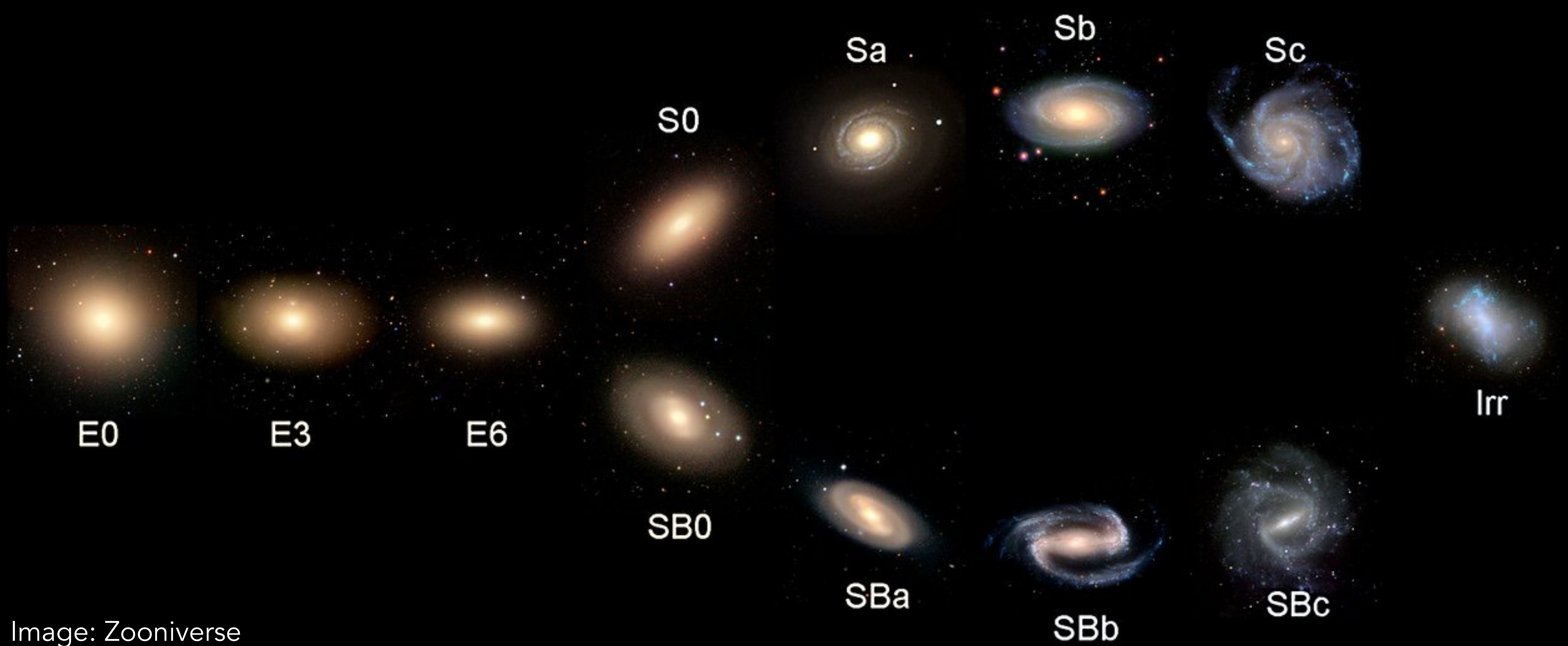


Image: Zooniverse

Observed spiral (disk) galaxies

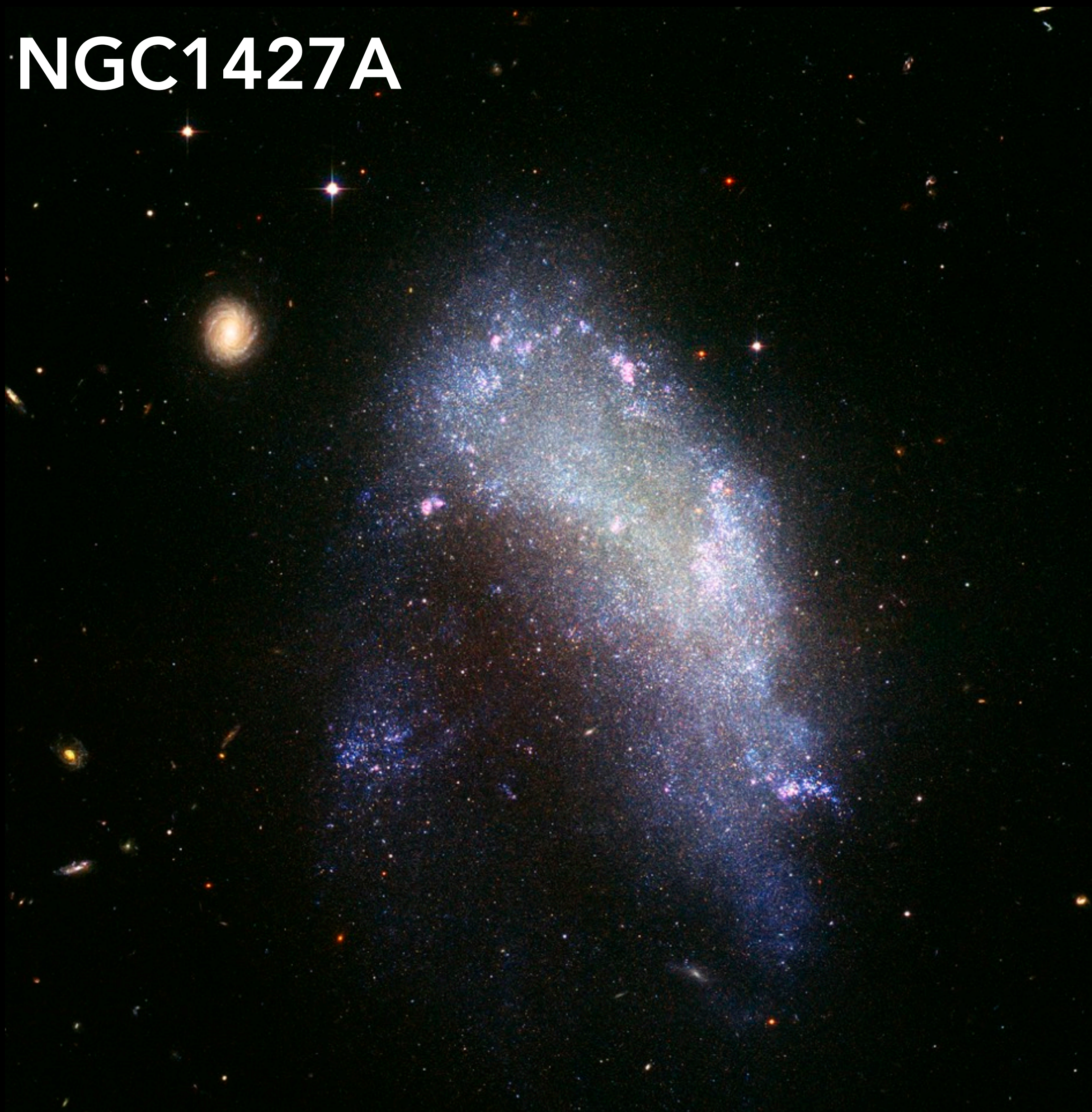
M102

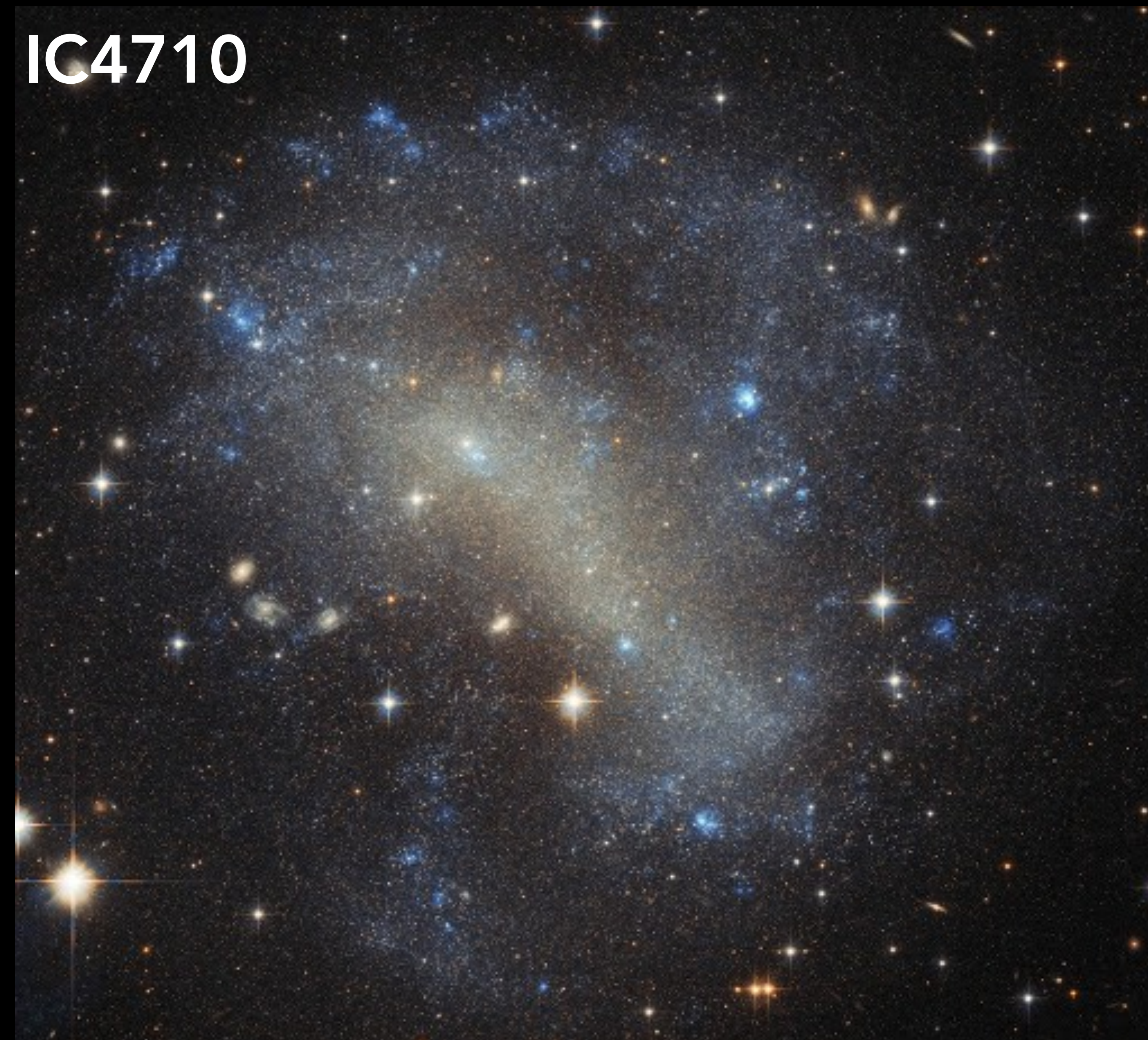
Hubble Space Telescope

Observed elliptical galaxies

Hubble Space Telescope

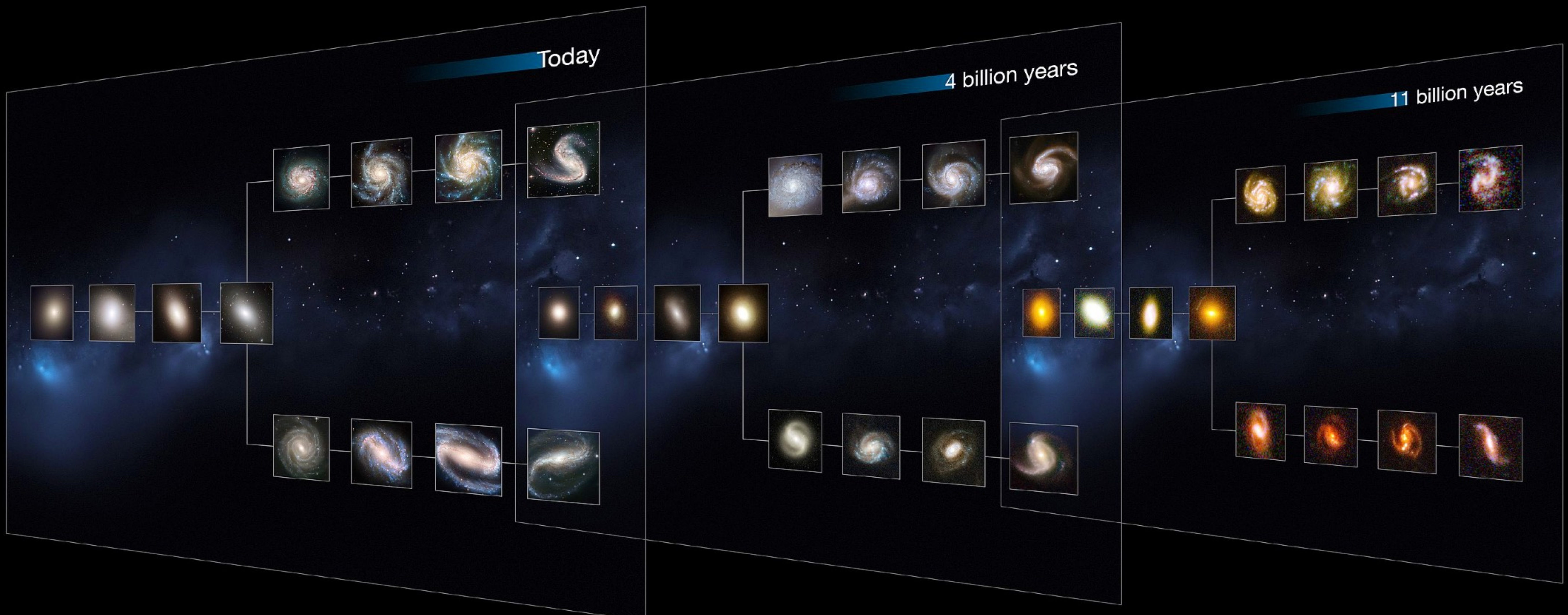
Observed irregular galaxies





Hubble Space Telescope

Hubble sequence across cosmic time

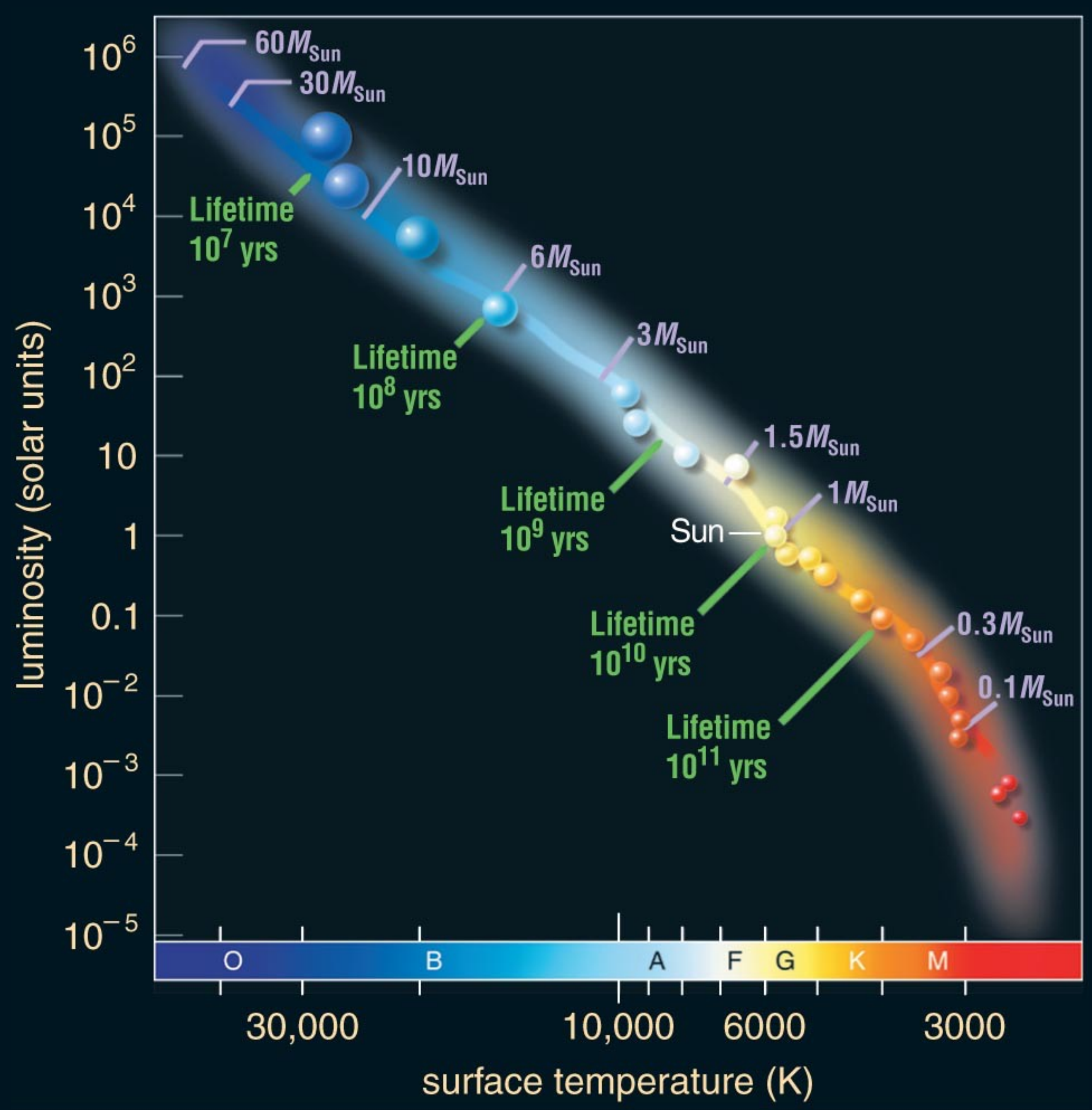


Wikipedia

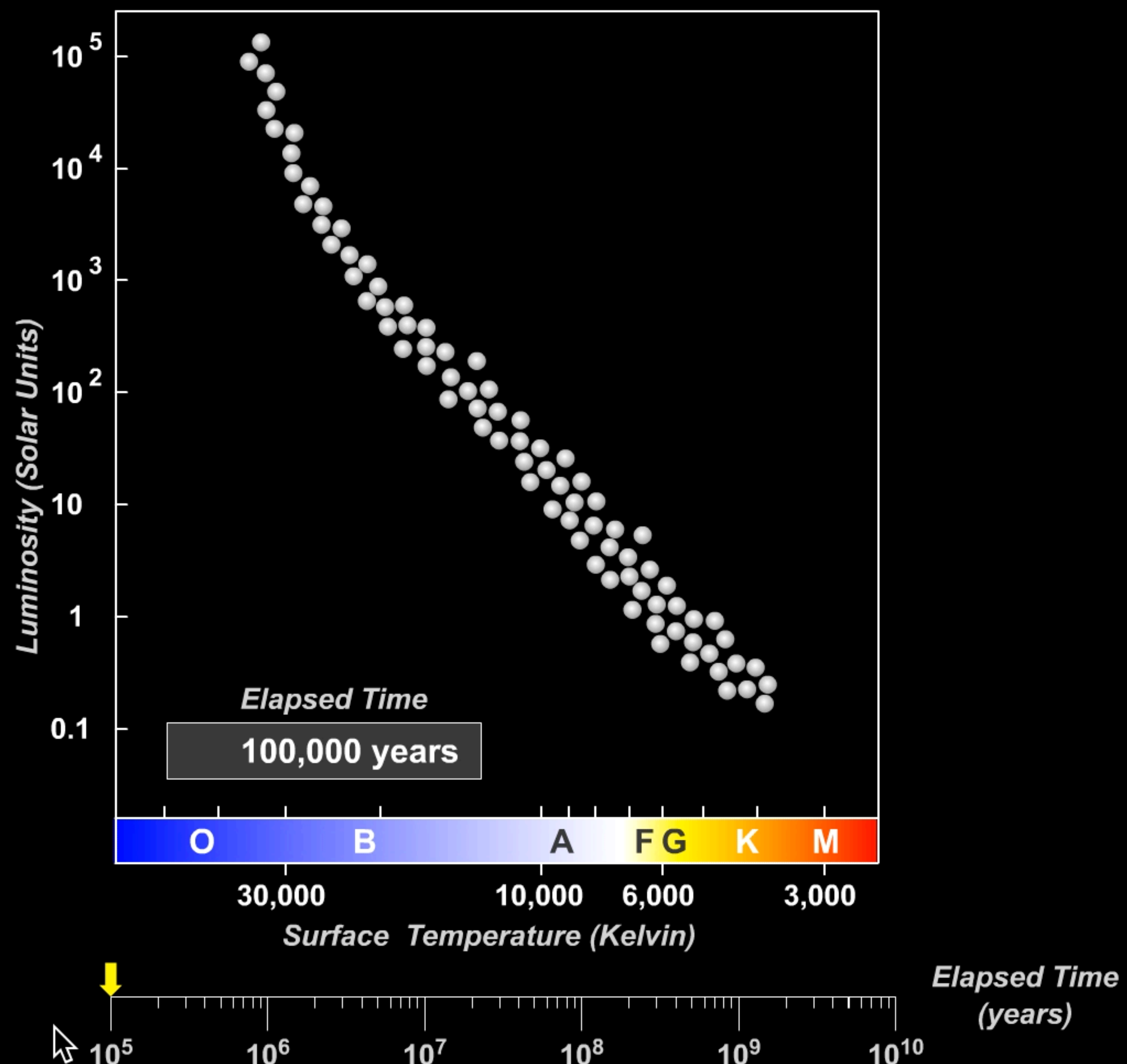
§2.5.2 • Correlations between morphology and other galaxy properties

Recap: Stellar lifetimes on the main sequence

- High-mass stars ($> 8\ M_\odot$)
  Lifetime <100 million years
- Intermediate mass stars (2-8 $M_\odot$)
  Lifetime 100 million to 1 billion yrs
- Low-mass stars (<2 $M_\odot$)
  Lifetime of 1 to 1000 billion yrs



Recap: The main sequence turn-off



Spiral vs. elliptical, red vs. blue

- **Color**
  - Smaller stars are redder and live longer, bigger stars are bluer and live shorter
  - Thus, as a stellar population ages, it gets more red ("red and dead")
  - Blue galaxies are actively forming stars whereas red galaxies are not
- **Shape**
  - Spirals tend to be very disk-like, whereas ellipticals are spherical to ellipsoidal
- **Correlations**
  - Elliptical galaxies tend to be red (old stellar population), spirals tend to be blue (forming stars)
  - However, there are intermediate stages to all of these classifications: red spirals, blue-ish ellipticals/irregulars, and everything in between

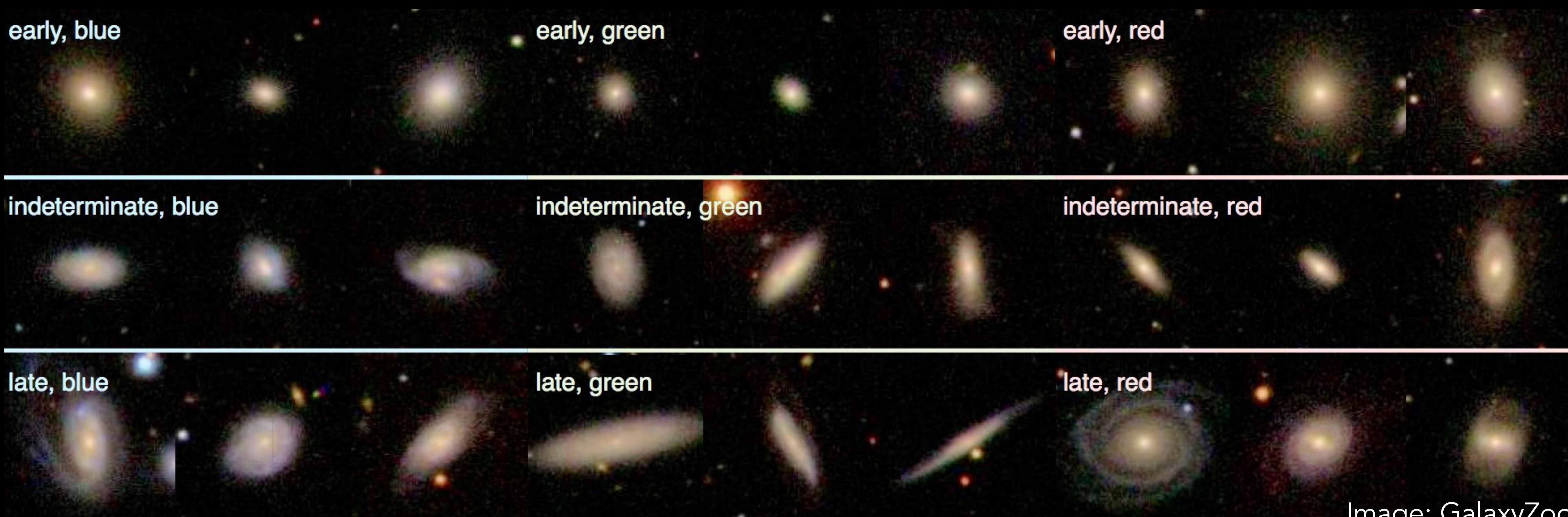
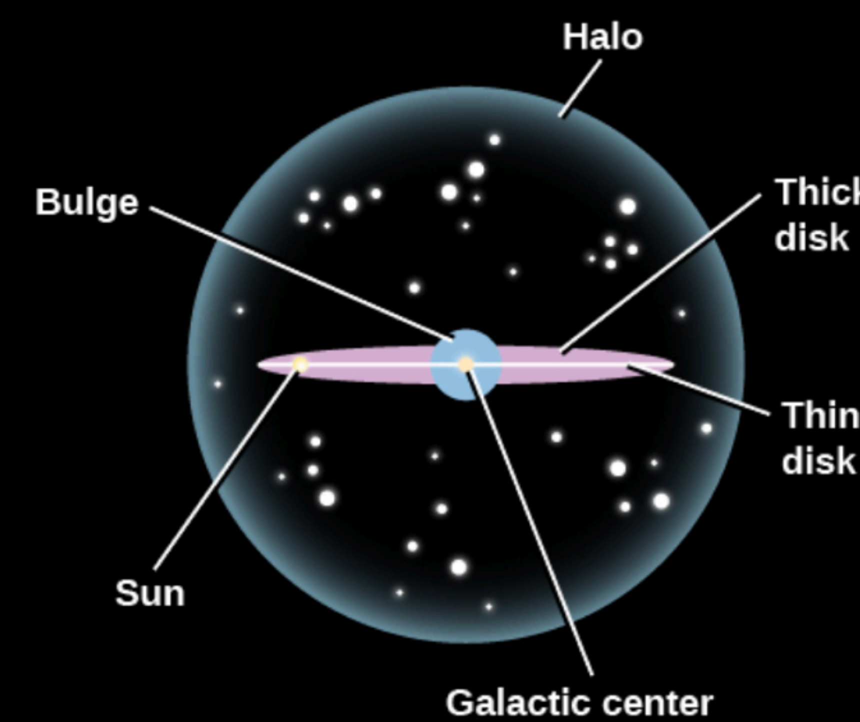


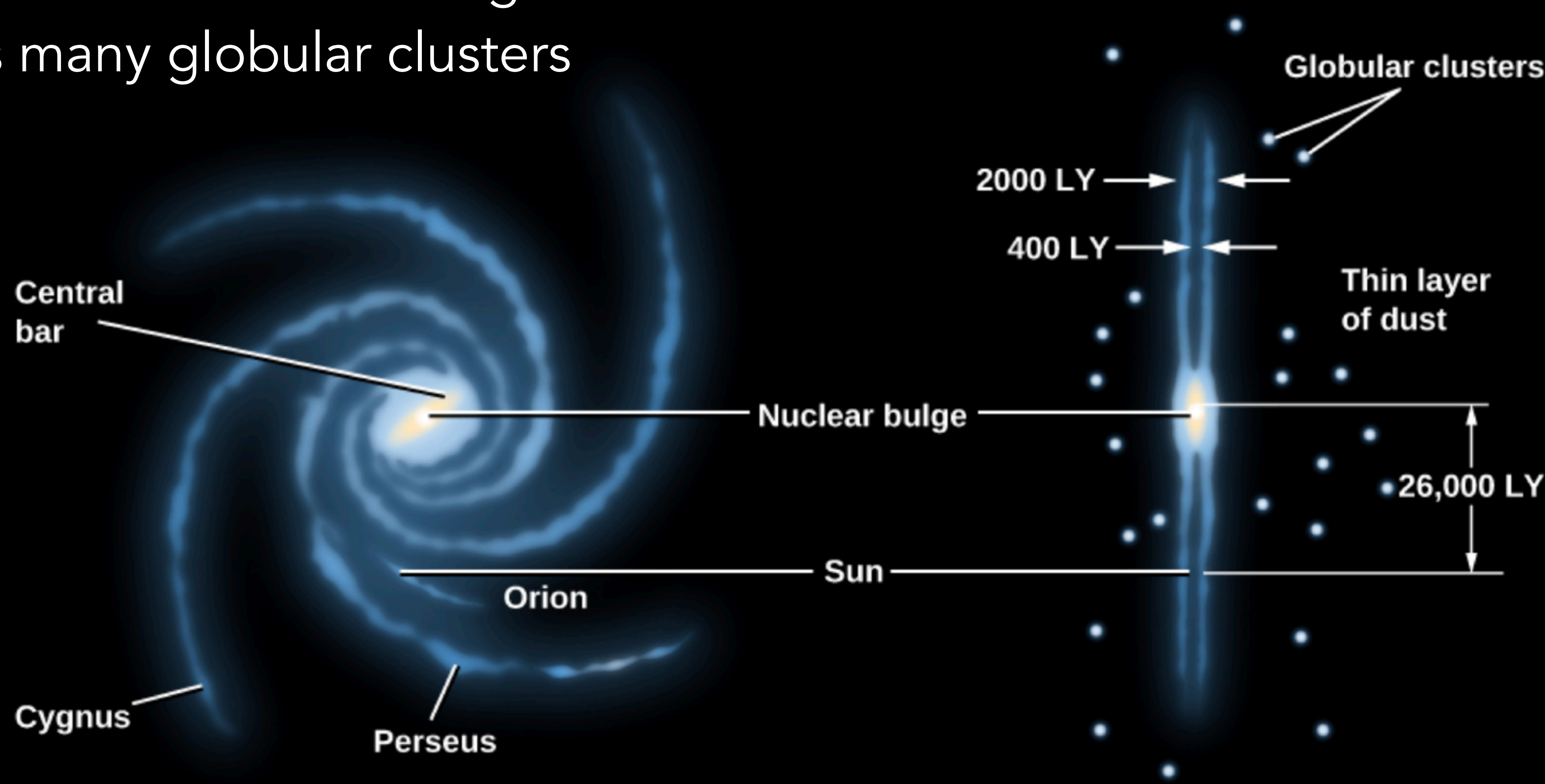
Image: GalaxyZoo

§2.5.3 • Morphology and dynamics: a preview

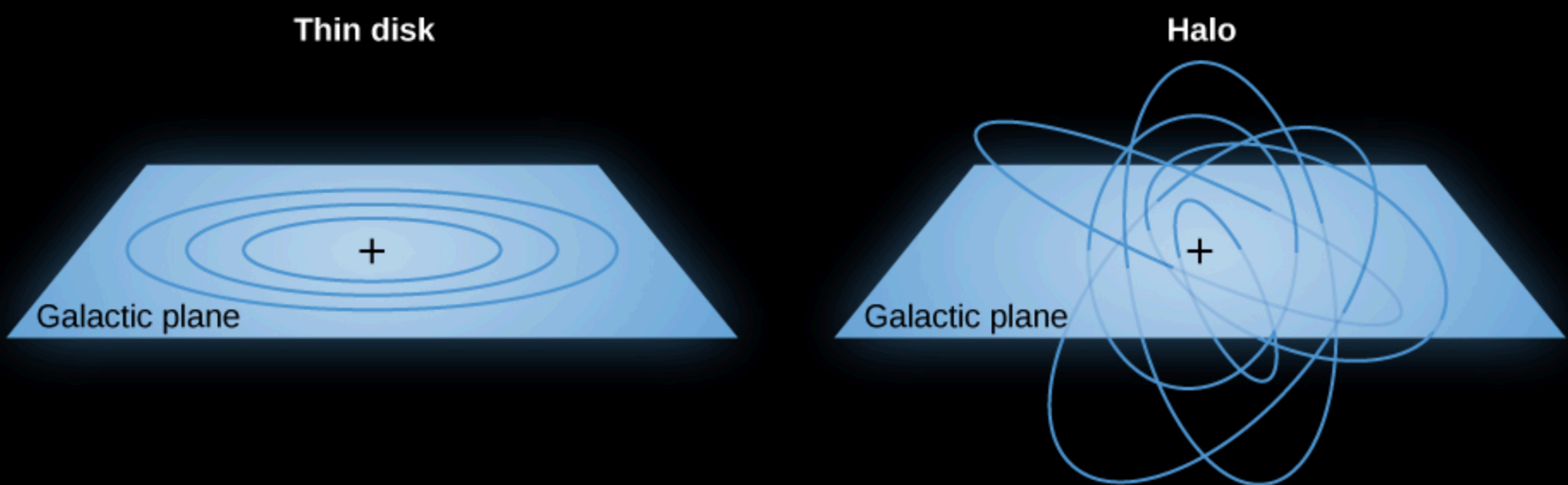
The structure of the Milky Way Galaxy

- The disk is very thin: about 100,000 ly wide and 2,000 ly thick
- Almost all young stars are found in the disk, within 100 ly of the plane
- Stars within about 10,000 ly from the Galactic center are not confined to the disk and “bulge” outward
- Some (mostly older) stars orbit in the larger stellar halo, which includes many globular clusters

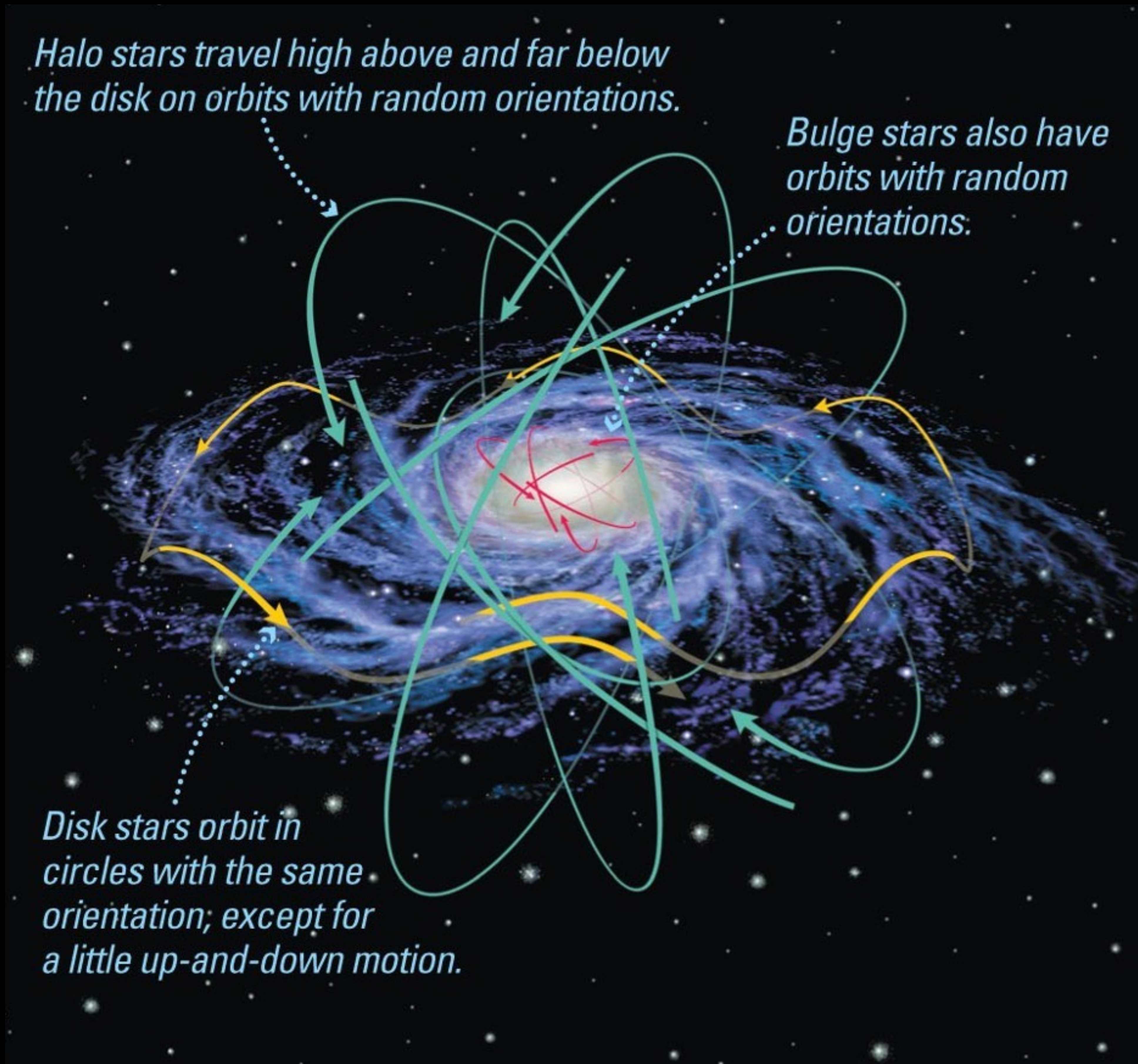




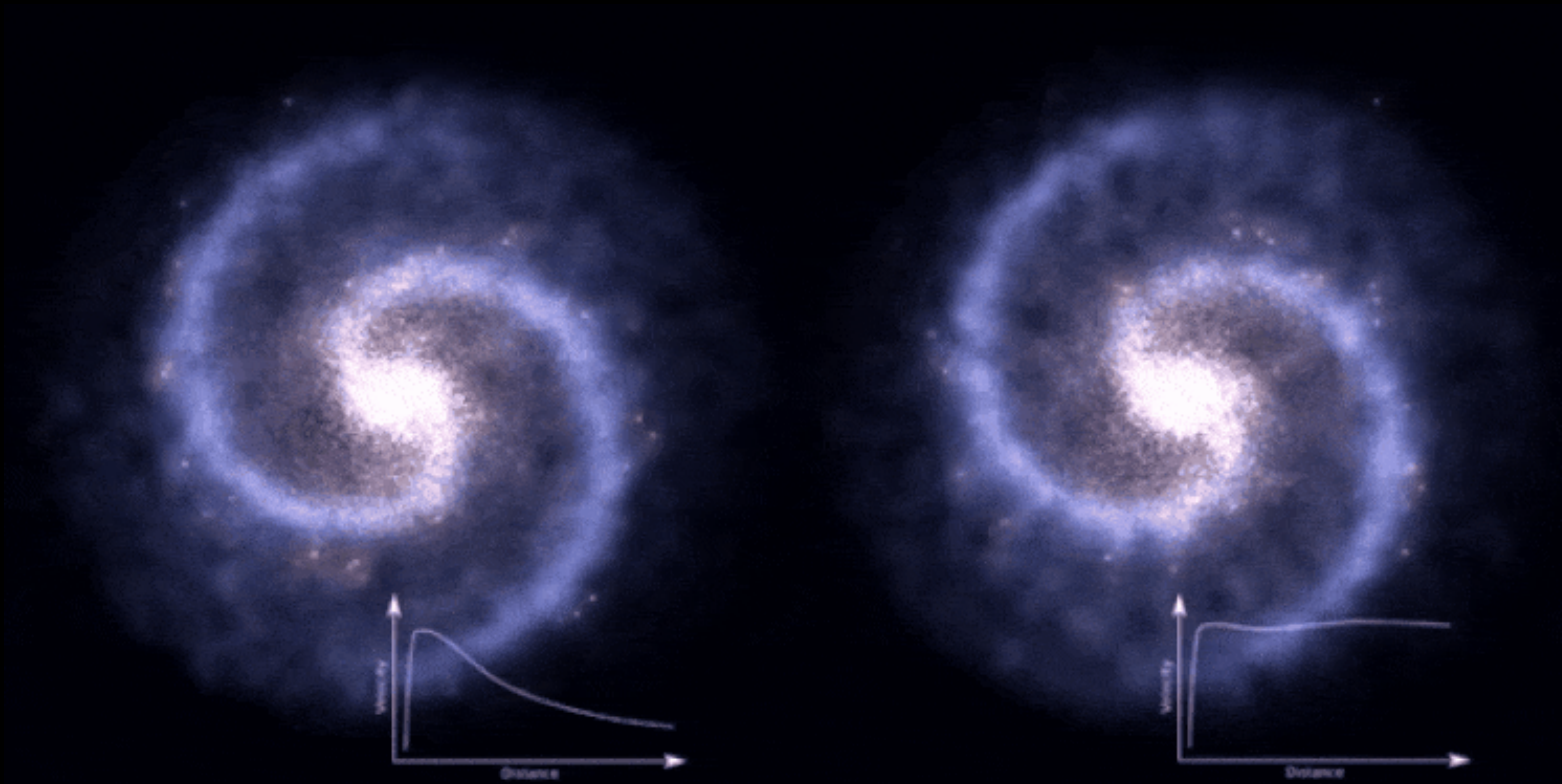
The structure of the Milky Way Galaxy



The structure of the Milky Way Galaxy



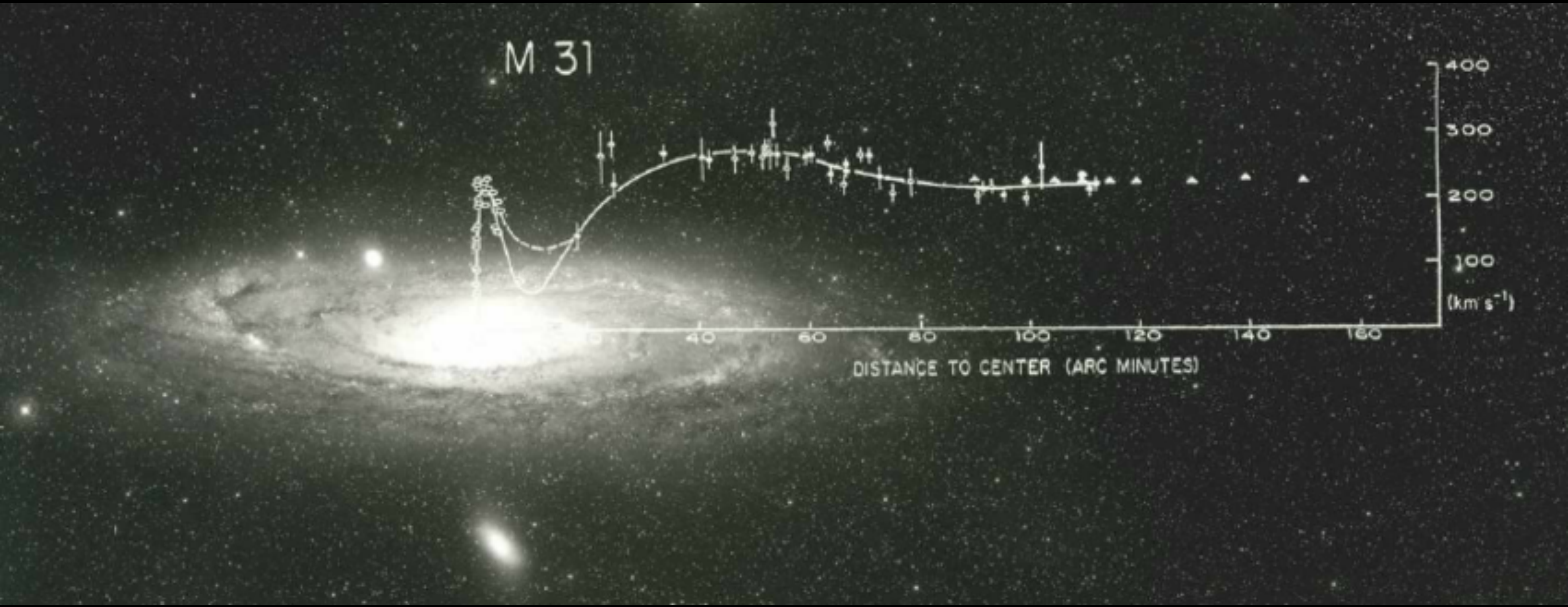
Rotation curves



Ethan Siegel

Measuring the total mass of galaxies

Vera Rubin



Rubin & Ford 1970

Reading

- CFN
  - 2.1: §6.6
  - 2.2: §C.2-C.4
  - 2.3: §3.1.2-4
  - 2.4: §3.5
  - 2.5: §3.1
- MvdBW
  - 2.1: §2.7-2.7.1
  - 2.2: §2.1
  - 2.3: §2.4.2
  - 2.4: §15.2.1
  - 2.5: §2.3.1